NASA's Nuclear Frontier

The Plum Brook Reactor Facility

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NASA's Nuclear Frontier

The Plum Brook Reactor Facility, 1941–2002

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Introduction

In 1953, President Eisenhower delivered a speech called "Atoms for Peace" to the United Nations General Assembly. He described the emergence of the atomic age and the weapons of mass destruction that were piling up in the storehouses of the American and Soviet nations. Although neither side was aiming for global destruction, Eisenhower wanted to "move out of the dark chambers of horrors into the light, to find a way by which the minds of men, the hopes of men, the souls of men everywhere, can move towards peace and happiness and well-being."[1] One way Eisenhower hoped this could happen was by transforming the atom from a weapon of war into a useful tool for civilization.

Many people believed that there were unprecedented opportunities for peaceful nuclear applications. These included hopeful visions of atomic-powered cities, cars, airplanes, and rockets. Nuclear power might also serve as an efficient way to generate electricity in space to support life and machines. Eisenhower wanted to provide scientists and engineers with "adequate amounts of fissionable material with which to test and develop their ideas."[2] But, in attempting to devise ways to use atomic power for peaceful purposes, scientists realized how little they knew about the nature and effects of radiation. As a result, the United States began constructing nuclear test reactors to enable scientists to conduct research by producing neutrons.

American scientists and engineers carried out the "atoms for peace" initiative at the nearly 200 research and test reactors built in the 1950s and 1960s. These types of reactors are very different from power reactors, which are built to produce power by converting radioactive heat into electricity. In contrast, research and test reactors are used for scientific and technical investigations. Research reactors help engineers design experiments and build better reactors, while test reactors generate powerful radiation fields that enable scientists to

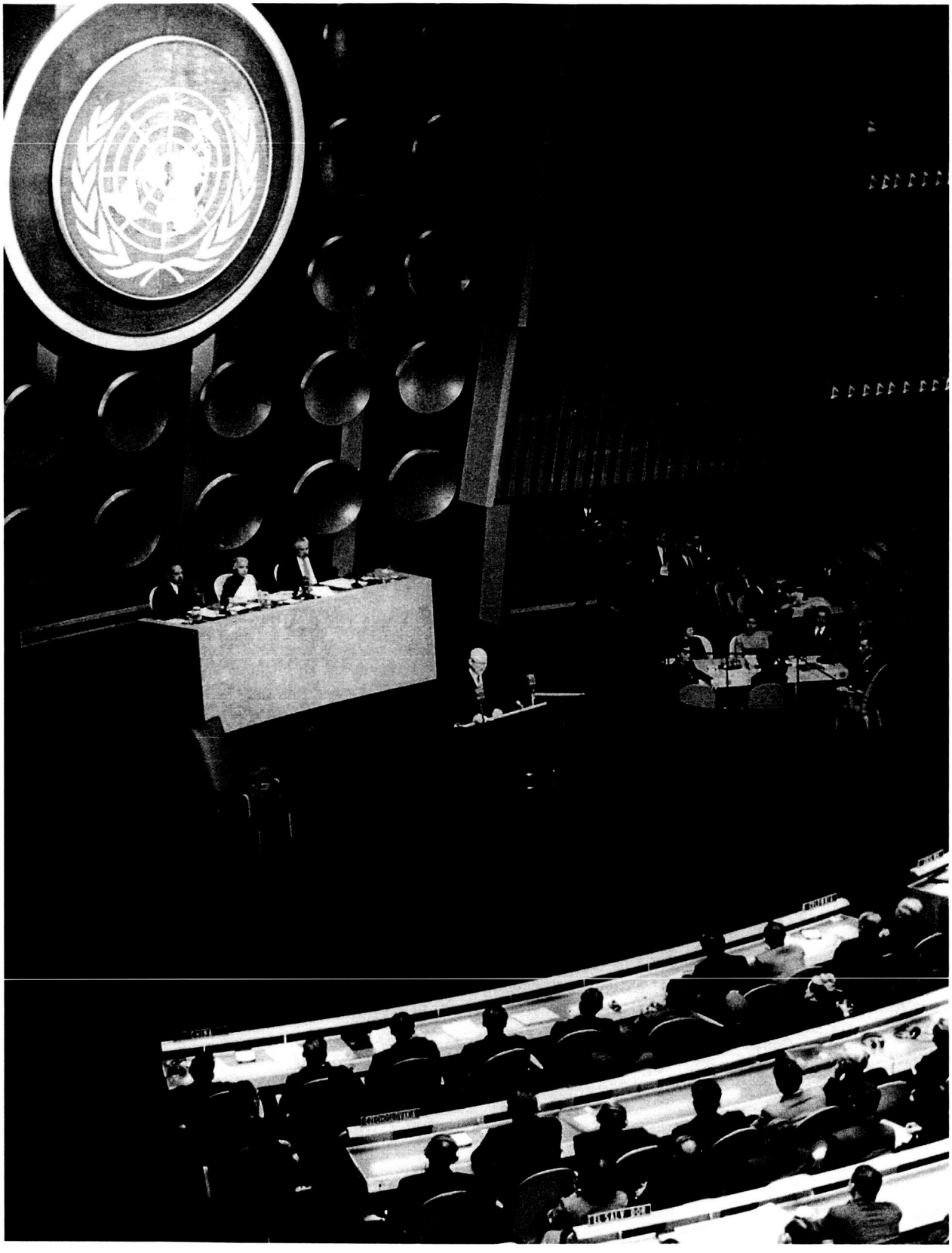

Image 2: In his 1953 "Atoms for Peace" speech at the United Nations General Assembly, President Eisenhower called for an international atomic agency so that "experts would be mobilized to apply atomic energy to the needs of agriculture, medicine, and other peaceful activities." (International Atomic Energy Agency)

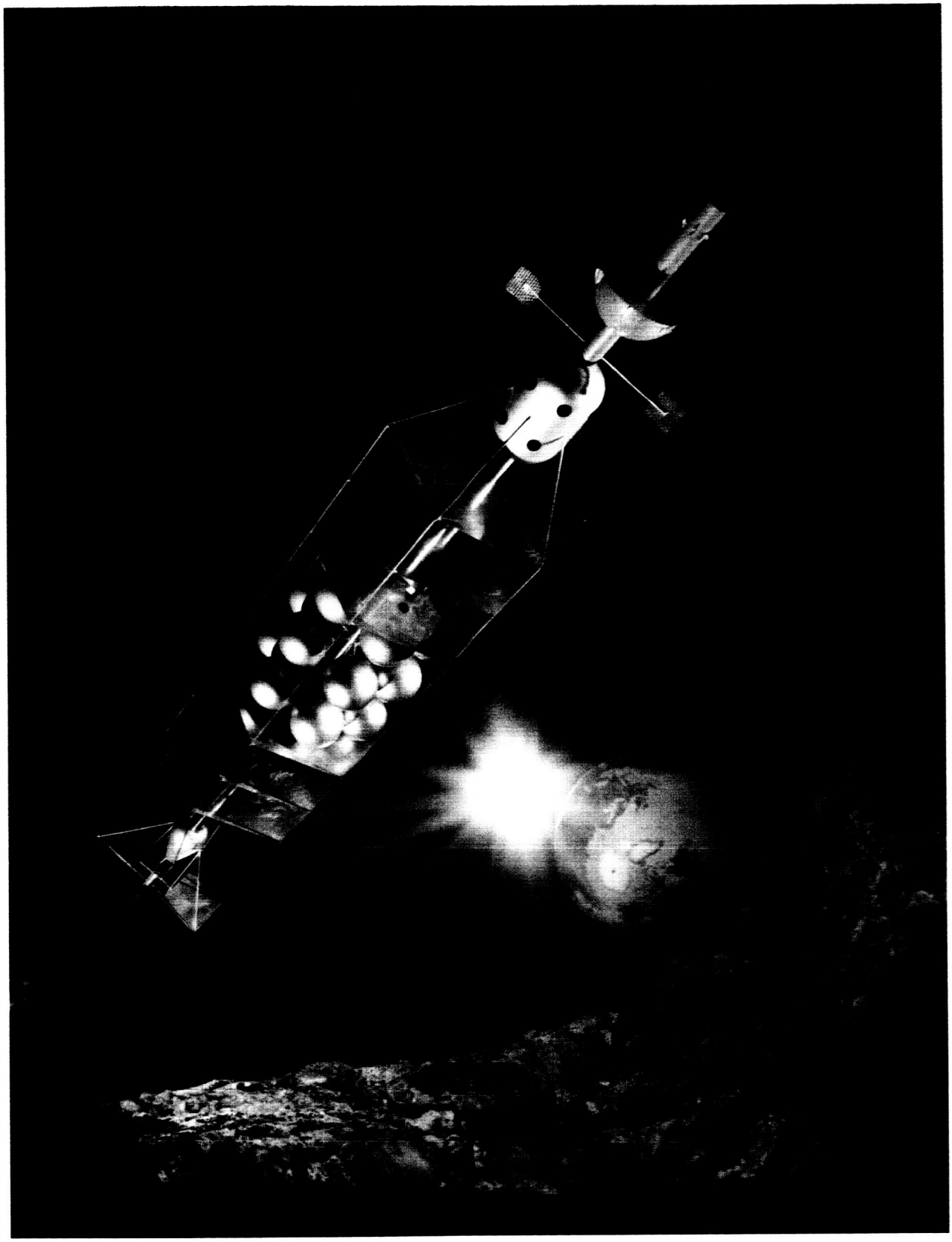

Image 3: Artist's conception of a piloted nuclear-powered spacecraft capable of exploring the solar system. (1959) (NASA C–1959–52113)

Image 4: Artist's conception of an atom-powered bomber capable of carrying its own fighter escort. The plane was described by Lee A. Ohlinger, atomic specialist for Northrup Aircraft, at a meeting of the Society of Automotive Engineers in New York (10 April 1956). Called "Project Opossum," the bomber would carry six fighters at subsonic speeds, cutting them loose and shifting into high in case of attack. (Copyright and permission courtesy of Bettmann/CORBIS)

study how materials respond to radioactive environments. Though commercial and academic institutions built some research and test reactors, the government supported the large majority of them. One of the most powerful in the world was the National Aeronautics and Space Administration (NASA) test reactor, located at Plum Brook Station in Sandusky, Ohio, near Lake Erie. From 1961 to 1973, this reactor was home to some of the most advanced nuclear experimentation in the United States. Engineer A. Bert Davis said of the work at Plum Brook, "We were young and eager and we felt like we were pushing back the frontiers of science."[3] The Plum Brook reactor became NASA's nuclear frontier—the boundary between what was known and unknown about the effects of radiation on materials.

This book is a visual history of the Plum Brook reactor, including numerous images and captions, a narrative history, and selected primary documents. It begins with the acquisition of the Plum Brook farmland by the government at the start of World War II and discusses its use as a significant ordnance works for the war effort. At the same time, scientists worldwide were making tremendous progress on a roughly fifty-year investigation of the mysterious world inside the atom and the enormous reserve of power it appeared to contain. This work culminated in the atomic bomb. After the war, as Plum Brook's ordnance factories went silent, scientists continued their pursuit of nuclear knowledge by constructing test reactors. One specific aim for this research in the 1950s was to build a nuclear-powered airplane. To support this effort, in 1956 NASA's predecessor, the National Advisory Committee for Aeronautics (NACA), began to design and build a massive test reactor at Plum Brook. By the time the reactor was completed in 1961, President Kennedy had suspended the nuclear

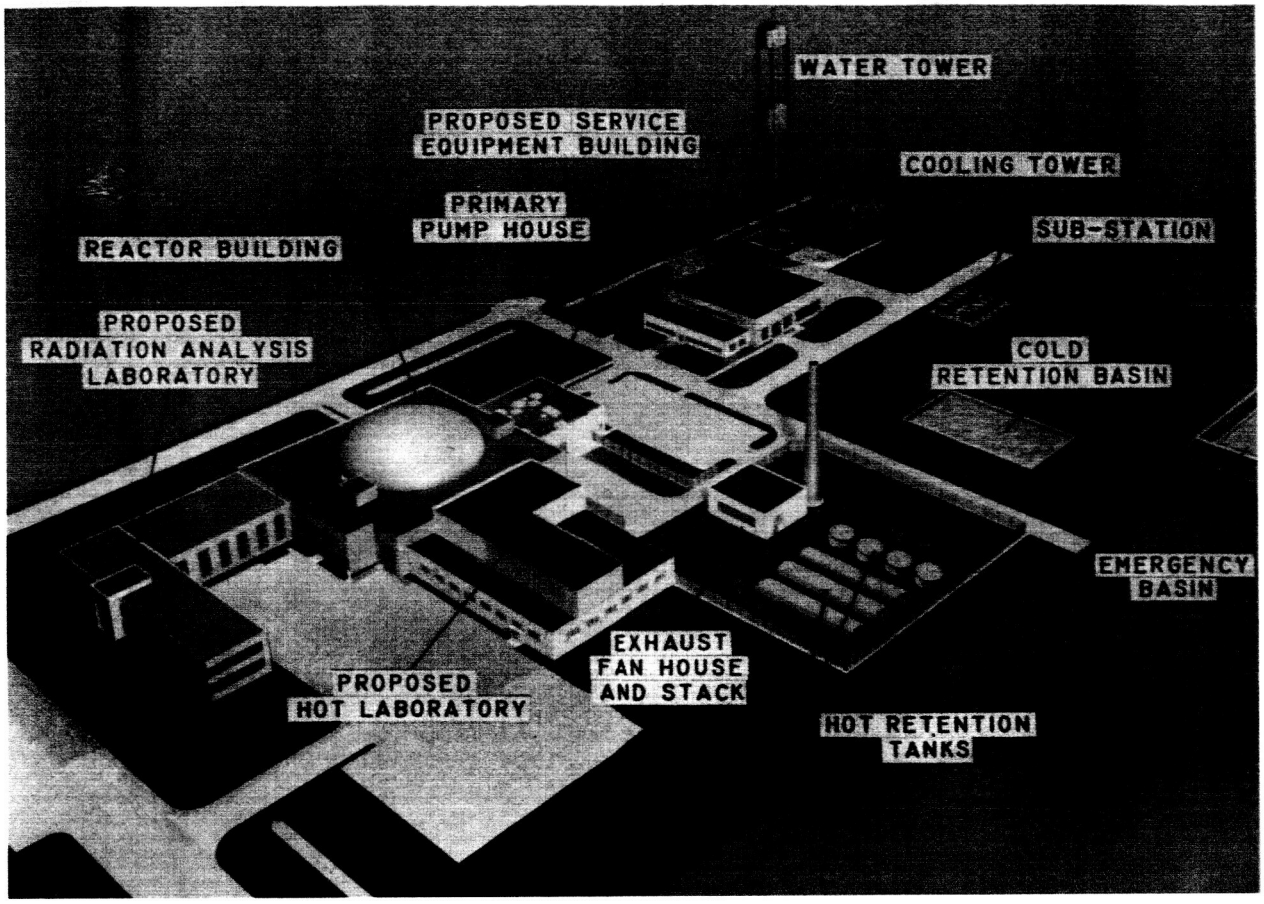

Image 5: Artist's drawing showing the layout of other Plum Brook support buildings and laboratories. At the time, several key buildings had yet to be built. (1957) (NASA C-2003-818)

aircraft program for safety and technical reasons. However, in its place he advocated an even bolder plan—a nuclear rocket. The Plum Brook Reactor Facility became one of the primary research facilities to test materials for this rocket. Working with contractors from Lockheed, Westinghouse, General Dynamics, and General Electric, scientists and engineers conducted ground breaking nuclear experiments.

Despite the promise of their work, many of the experiments were never concluded. In 1973, just over a decade after Kennedy first extolled the nuclear rocket's importance, the project shared the fate of the nuclear airplane. In the post-Apollo era, NASA terminated costly, long-term, nonreusable projects like the nuclear rocket in favor of programs that appeared to have greater immediate payoff like the Space Shuttle. Two weeks after Apollo's last mission, Plum Brook was ordered to shut down its reactor. The entire facility was maintained in a standby mode (under a "possess but do not operate" license) for nearly a quarter century. In 1998, a decommissioning plan was formulated to demolish the reactor piece by piece, until nothing would be left but bare land, suitable once again for farming. Despite now being closed for over thirty years, it remains the eighth-largest test reactor that the United States has ever built.

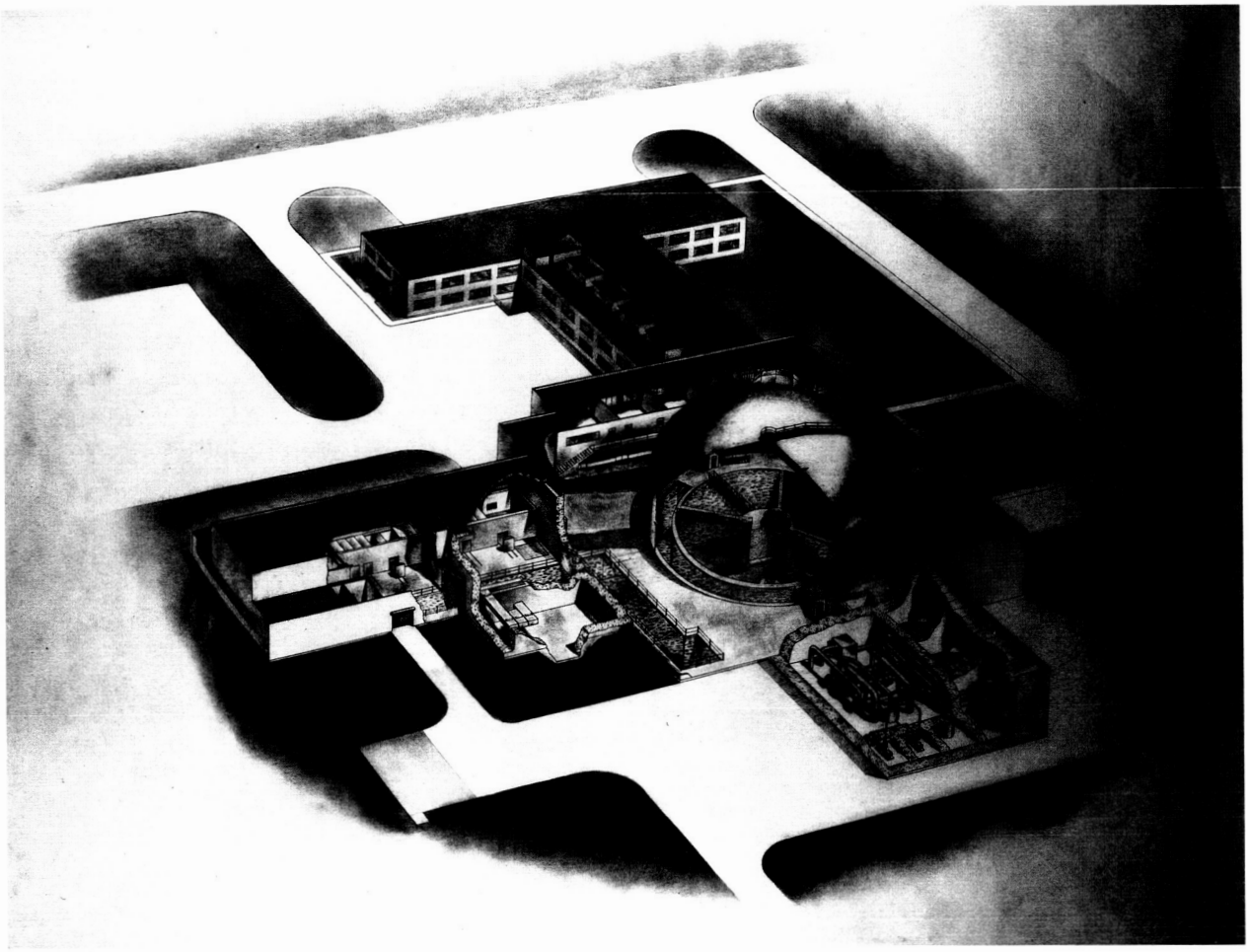

Image 6: Plum Brook reactor primary buildings with a cutaway of the containment vessel revealing the quadrants, the reactor pressure tank, and the lily pad. It was called the lily pad because, with water in the quadrants, the circular center resembled "a lily pad floating on water." (1956) (NASA C-1956-42673)

Archivist Robert S. Arrighi gathered a photographic database, collected artifacts for a museum display, and assembled documents in a collection destined for the National Archives and Records Administration. Historian Mark D. Bowles interviewed many of the people who had worked at the reactor, analyzed the documents, and began writing a scholarly book-length history of the facility (the forthcoming *Reactor in the Garden*). The authors hope that their combined efforts have resulted in a visually exciting and intellectually accessible monograph that recounts the pioneering research of a committed group of NASA scientists and engineers working in the nuclear frontier.

The authors would like to thank Dr. Virginia P. Dawson at History Enterprises, Inc., for her valuable insight into NASA history and her comments on successive drafts of this manuscript. They also thank Kevin Coleman of NASA Glenn Research Center for his coordination of this project and his advice and assistance throughout all phases of the research, writing, and photograph gathering. The authors also acknowledge the valuable help of Deborah Demaline, Jim Polaczynski, Quentin Schwinn, Mark Grills, and Bruce MacGregor from Indyne Inc.; Michael Blotzer, chief of the Glenn Research Center Environmental Management Office; Rich Kalynchuk from Science Applications International Corporation; Project Manager Timothy J. Polich and Senior Engineer Keith M. Peecook from the Plum Brook Reactor Facility Decommissioning. Steve Dick, NASA Chief Historian, Stephen Garber, Jennifer Troxell, and Katrina Thompson from the NASA History Office; Galen Wilson and Scott Forsythe from the National Archives and Records Administration; Nan Card from the Rutherford B. Hayes Presidential Center; Deborah A. MacDonell from the United States District Court

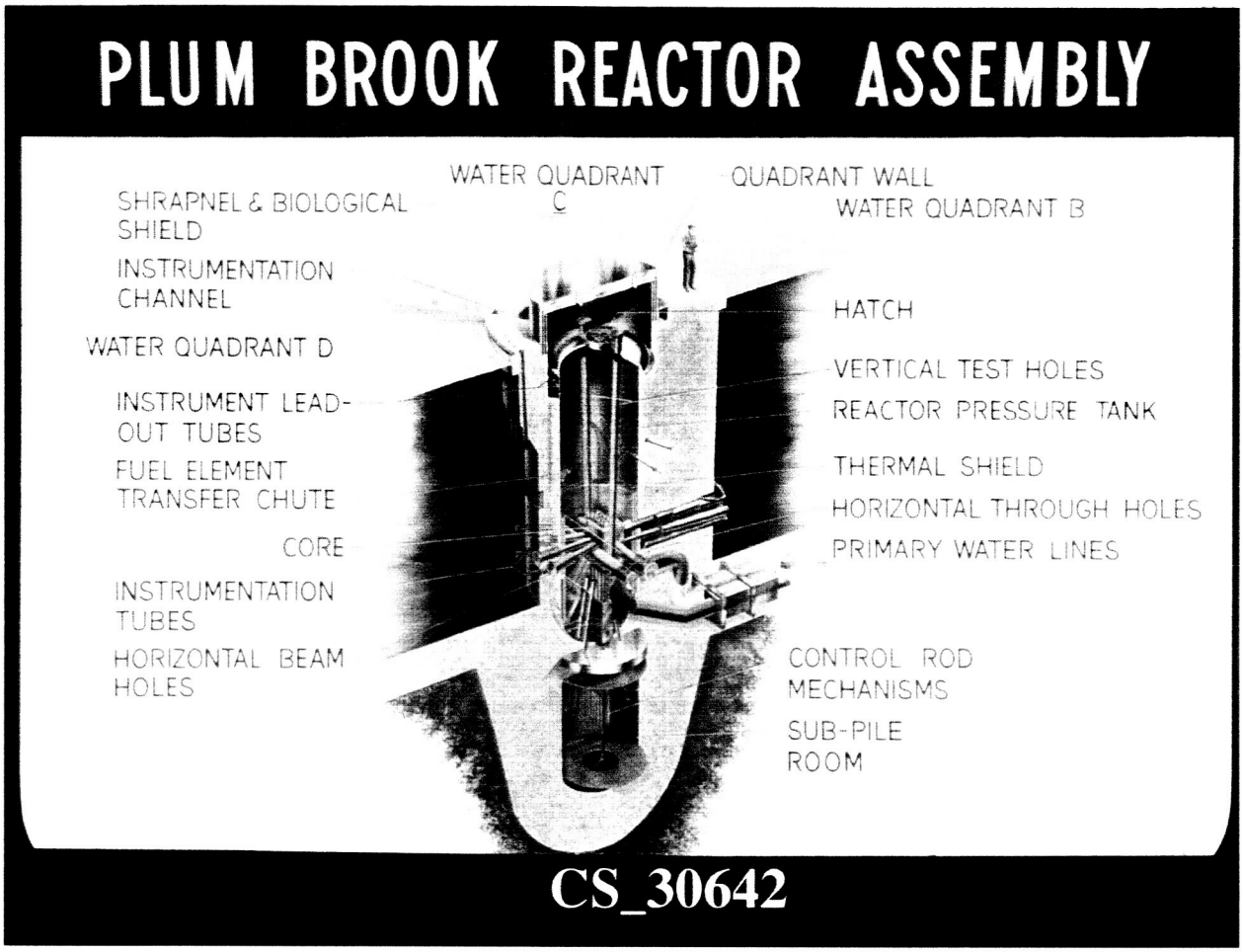

Image 7: Cutaway drawing of the Plum Brook reactor assembly within the pressure tank. The drawing reveals an array of test holes, the core, subpile room, control rods, water lines, etc. The tank was surrounded by four shielding quadrants, three containing water. Quadrant B was constructed with extra concrete shielding so the water was not necessary. This construction provided unique capabilities for handling experiment packages. Despite the significance of this feature, the artist erroneously depicts Quadrant B as being filled with water. (NASA CS-30642)

Northern District of Ohio (Toledo); Linda Gattshall from the Milan Public Library; Margaret Baughman from the Cleveland Public Library Photograph Collection; Joanne Cornelius from the Cleveland State University Special Collections Department; Jerome Cooke from the Department of Energy; and all of the retirees from the Plum Brook Reactor Facility who graciously gave their time to be interviewed for the history projects. Lynn Patterson provided excellent transcriptions for all the interviews conducted in this book. Melissa Kennedy at NASA Headquarters created an initial design, at NASA Glenn, Kelly Shankland redesigned and laid out the complete monograph, Patty McCredie was the editor, and Lorraine Feher was the proofreader. A special thank-you goes to Hap Johnson, H. Brock Barkley, and Harry Finger, who supplied documents and photographs from their personal files.

A debt of gratitude is extended to the manuscript reviewers (anonymous peer-reviewers and NASA and former Plum Brook reactor employees) who provided important suggestions to improve this manuscript. The NASA and reactor employees included H. Brock Barkley, Earl Boitel, Bill Brown, Jack Crooks, Don Johnson, Jack Ross, and Dean Sheibley.

A special recognition goes to Olga M. Dominguez, Deputy Assistant Administrator for Institutional and Corporate Management at NASA Headquarters in Washington DC, who without her support, dedication, and foresight to preserve the history of this unique facility, this document would not have been possible.

Obtaining the Land

In early 1941, Fred C. Baum was working on his 110-acre farm in Erie County, Ohio, just like he had every day for the previous twenty years. He was a typical small farmer, raising cows, cultivating his fields, and tending to his 120-tree apple orchard. He and his family lived in an idyllic country house near his crops and livestock. Several acres of beautiful shade trees surrounded the area and a babbling stream named "Plum Brook" ran through the center of the property. Though Baum's farm was a thriving enterprise providing a good living for his family, his career as a farmer ended unexpectedly that spring, before he could even harvest the year's crop. His fields were destroyed, buildings razed, and livestock slaughtered, as the United States government acquired his property in the name of military preparation. For compensation the government land agents offered the Baum family $18,375 and told them to vacate immediately.[4]

With World War II spreading throughout Europe, American political and military leaders began to prepare the United States for the material demands of conflict. It was still many months before the bombing of Pearl Harbor, but the government began laying the infrastructure for the war. This infrastructure took the form of seventy-seven ordnance factories built throughout the country, primarily on the land of former farmers. In the span of just a few months in the spring of 1941, the government's land agents took possession of 44 million acres of land (roughly the size of all the New England states) formerly owned by private citizens. In Erie County the government exercised its power of eminent domain and forced over 150 Ohio farming families, including the Baum family, to sell 9,000 acres of land. Baum's farm became part of the future home of the Plum Brook Ordnance Works.

The United States military designated Plum Brook as one of its most important sites for the development of gunpowder. It became one of the three largest suppliers of trinitrotoluene (TNT) for

Image 8: Descendants of original 1812 Firelands settlers owned much of the property that became Plum Brook Station. Years of commitment and investment in the land had resulted in abundant crops and a strong community. In early 1941, federal agents arrived, and in April, 150 families were forced to sell out and leave the land that had been theirs for generations. Courtesy of Henry Pfanner.

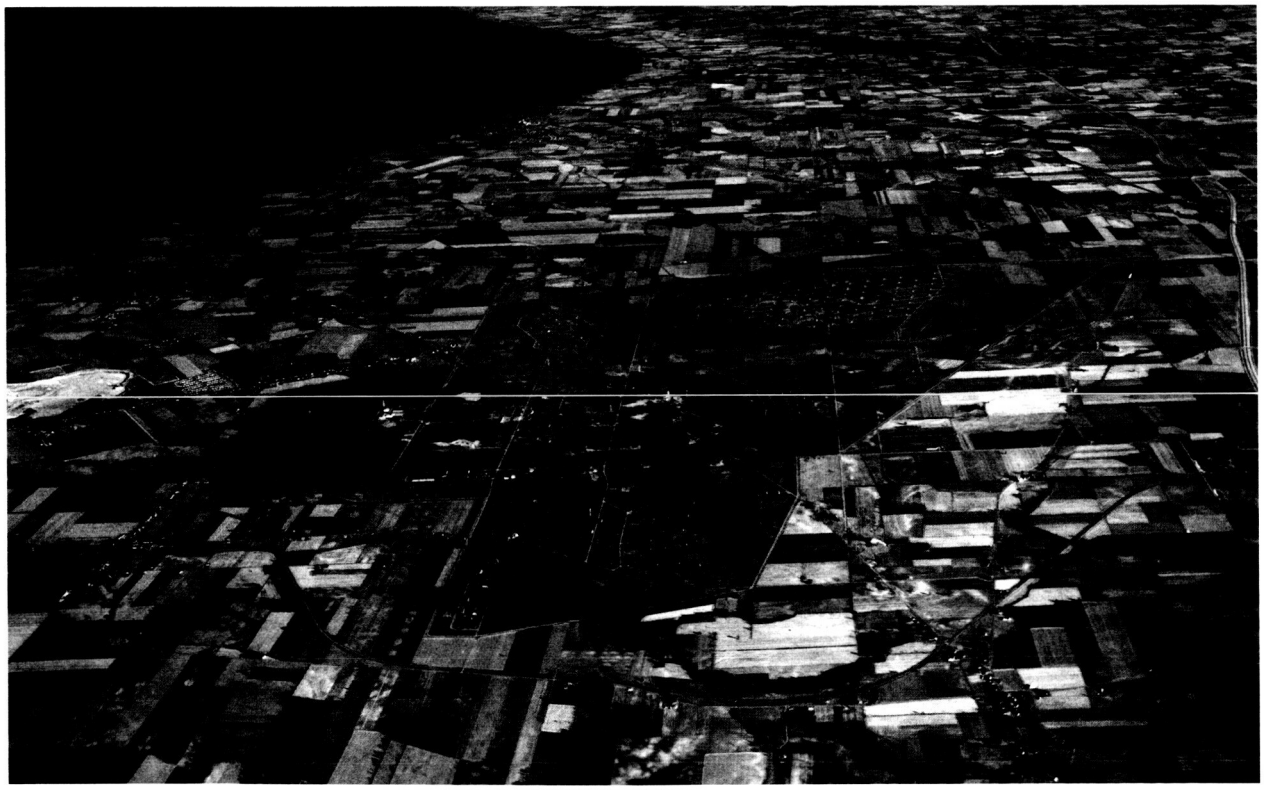

Image 9: Plum Brook Station seen in the context of Sandusky's unique location near Lake Erie. It is in the heart of some of the region's most fertile farmland. However, access to five highways, in addition to its secure distance from the borders, made it a perfect location for an ordnance facility. (NASA C–1960–55682)

Image 10: The Plum Brook Ordnance Works administrative building, medical services building, guard tower, and other structures during World War II. Just months prior to this photograph, this had all been farmland. Courtesy of Corps of Engineers, U.S., Army. (No. 1238–12, 1944)

Primary Document #1

The following document is Fred C. Baum's protest in a district court that the government was not providing fair compensation for the forced acquisition of his lands. The government was offering $18,500 and Baum believed that a fair price would be $35,929 for land that included a two-story brick home with ten rooms, two barns, milk house, hog pen, 120-tree apple orchard, thirty-one cows, twenty-two hogs, two acres of woods, and diversified crop production in his fields. Ten families went to court to get more money. Baum's was the only case in which the jury ruled in favor of the defendant; it awarded him $31,700, just $4,000 less than he was seeking. No other defendants were awarded anything close to what they held their land to be worth. The government believed that Baum won his case because of a disposition on the part of the jury to favor the landowner without giving just consideration to the testimony presented by government experts. This jury decision was eventually upheld and Baum received his money. These documents can be found at Record Group 21, Records of the District Courts of the United States, Toledo, Civil Case 4627, U.S. vs. 1140.375 Acres of Land, et al., National Archives-Great Lakes Region (Chicago).

September 19, 1941

IN THE DISTRICT COURT OF THE UNITED STATES FOR THE NORTHERN DISTRICT OF OHIO, WESTERN DIVISION

Fred C. Baum presents to the Honorable Court that on or about the 21st day of June, 1941, the United States of America instituted condemnation proceedings as herein entitled, seeking to acquire certain land in Erie County, Ohio, for federal building site purposes, more specifically designated as the Plum Brook Ordnance Site, a portion of which land designated as Parcel I, and fully described in the petition referred to, was in the name of this applicant; and that on or about the 23d day of June, 1941, by order of this Court, the immediate possession of this land referred to was taken by the United States of America.

The applicant further states that subsequently negotiations were entered into for the payment of said land with representatives of the United States Government, but that a price judged to be fair compensation for the taking of said property could not be agreed upon and that consequently the fair value of said property is to be determined at a later date by this Honorable Court and a Jury impaneled for such purposes.

The applicant further states that the United States of America considered that Eighteen Thousand, Five Hundred Dollars ($18,500.00) was a fair and reasonable price for the taking of said land as aforesaid, and has deposited with the Clerk of this Court said amount to the credit of this applicant.

This applying defendant has been ordered to vacate said premises by officials of the War Department of the United States, but is without sufficient funds to purchase or lease other lands and housing facilities to which he might move his family and his furniture and equipment.

IN THE UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF OHIO
WESTERN DIVISION

UNITED STATES OF AMERICA,

Petitioner,

vs.

1140.375 acres of land, more or less, in Erie County, Ohio, H. A. Druckenmiller and Carrie Druckenmiller, et al.,

Defendants.

CIVIL ACTION NUMBER 4627

SUPPLEMENTAL BRIEF ON MOTIONS FOR NEW TRIAL FILED BY ANNA BOUY, AMELIA KROMER, CARRIE KROMER, GEORGE D. BEATTY AND EMMA HERMES.

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WAR DEPARTMENT

WASHINGTON

The Honorable,
The Attorney General,
Washington, D. C.

AUG - 9 1941

Dear Mr. Attorney General:

Reference is made to letter from this Department, dated June 17, 1941, requesting institution of condemnation proceedings for the acquisition of 1,140.375 acres of land located in Erie County, State of Ohio, for use in connection with the expansion of the Plum Brook Ordnance Plant.

Pursuant to the provisions contained in the Act of Congress approved February 26, 1931 (46 Stat. 1421; 40 U. S. C. sec. 258a), and under the further authority of the Act of Congress approved August 18, 1890 (26 Stat. 316), as amended by the Acts of Congress approved July 2, 1917 (40 Stat. 241), and April 11, 1918 (40 Stat. 518; 50 U. S. C. sec. 171), which acts authorize the acquisition of land for military purposes, and the Act of Congress approved April 15, 1941 (Public No. 29 - 77th Congress), which act appropriated funds for such purposes, it is requested that you cause the enclosed declaration of taking to be filed in condemnation proceedings now pending for the acquisition of the fee simple title to the land above referred to, subject, however, to all existing easements for public roads, highways and public utilities.

Said lands are more particularly described in the enclosed declaration of taking, executed by the Secretary of War on August 7, 1941. The declaration of taking sets forth the names of the purported owners of the land and the amount ascertained as just compensation for the taking, namely $9,950.00, check for which amount, payable to the order of the Clerk of the United States District Court for the Northern District of Ohio, Western Division, is enclosed for deposit in the Registry of said Court.

Attention is invited to the fact that the enclosed declaration of taking covers only a portion of the lands involved in the pending proceedings.

Sincerely yours,

HENRY L. STIMSON

Secretary of War.

2 Incls.
#1 - Check
#2 - Dec. of Tak. (4)

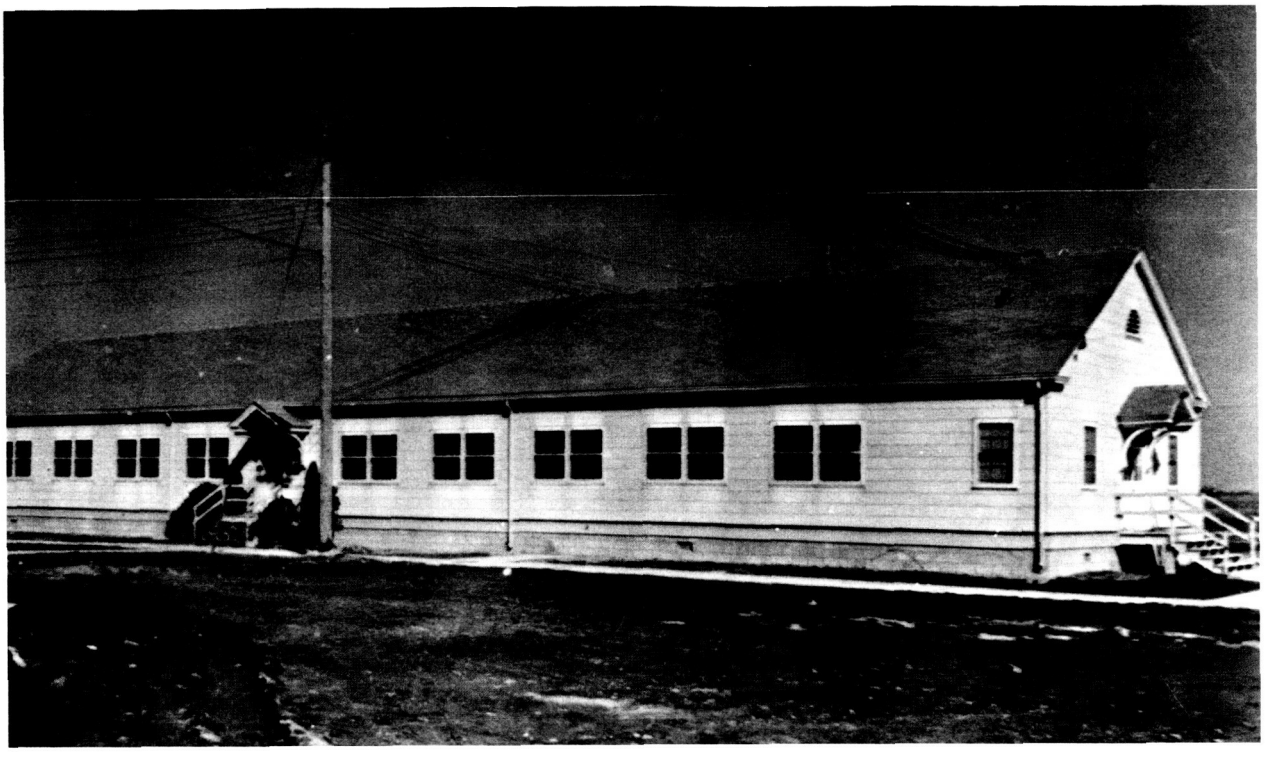


Image 11: The Plum Brook cafeteria building, a typical Ordnance Works structure. Plum Brook's ordnance buildings were built for functionality, not style. Although these structures were built to last five years, many survived much longer, and this building is today used by the Perkins School District. Courtesy of Corps of Engineers, U.S. Army. (No. 3–42, 1944)

Image 12: The Plum Brook cafeteria in the basement of Building 1. A painting of the Plum Brook Trojanair appears on the far wall. The B-17 bomber was built with war bonds purchased by Plum Brook Ordnance Works employees during one of their numerous bond drives. Courtesy of Corps of Engineers, U.S. Army. (No. 21748, 1944)

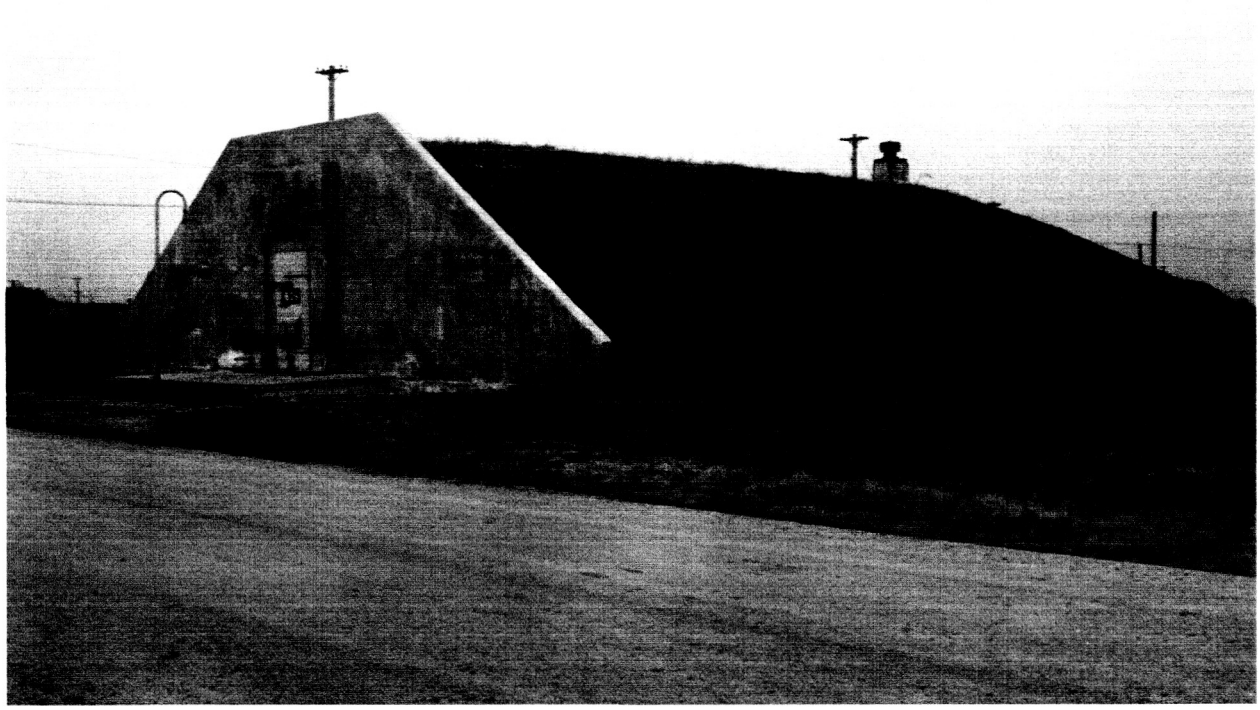


Image 13: One of ninety-nine bunkers used to store powder at Plum Brook's southwest corner. These structures function today as naturally climate-controlled warehouses for federal records. Courtesy of Corps of Engineers, U.S. Army. (No. 21762, 1944)

the nation, producing nearly one billion pounds between 1942 and 1945. Aesthetics, not surprisingly, were not considered important in the construction of most ordnance facilities. "There are to be no high falutin gargoyles on these buildings,"[5] remarked Major General Charles M. Wesson, chief of ordnance, in July 1940. Emphasis was placed on functionality, stability, and speed in construction. Most of the buildings at Plum Brook were considered temporary, with an expected lifespan of five years.[6] All in all, eight major buildings were erected at a cost of $7,851,335.[7]

While most of the buildings at ordnance facilities were hastily built with inexpensive construction materials, the igloos were a notable exception. The igloos (so named because they looked like Eskimo shelters) were solidly built storage facilities that Plum Brook used to house its explosives. They were concrete with reinforced steel structures, shaped like half-barrels lying sideways in the ground, and covered with a thick layer of sod. Two lightning rods protected them during electrical storms. Though they were designed to explode upward and not sideways, all ninety-nine of them had to be isolated from each other by at least 400 feet on each side and 800 feet from the front and rear to prevent a dangerous chain reaction if one of them ignited.

Plum Brook's first line production of TNT began on 15 November 1941, just twenty-two days before the Japanese unleashed a surprise attack on Pearl Harbor.[8] The prime operating contractor was the Trojan Powder Company of Allentown, Pennsylvania. Once operational, Plum Brook produced over 400,000 pounds of explosives per day.[9] The workers did everything that they could to support the war effort. Not only were they committed to performing their jobs, but they also pooled their money together to buy war bonds. One Plum Brook bond campaign set a goal of raising enough funds to purchase a $350,000 military airplane. The plane, a flying fortress, was christened "The Plum Brook Trojanair" before its first flight.

Sandusky, Ohio **PBOW NEWS** November 21, 1942

TROJAN TRIUMPHS!

$396,000 WAR BOND PURCHASES BY EMPLOYEES ENDS SEVEN MONTHS' CAMPAIGN TO BUY FLYING FORTRESS

RECEIVE PRAISE FOR ACHIEVEMENT

DOWN PAYMENT ON HAND FOR SECOND 'FORT'

Trojan employees buy a flying fortress!

Yes, with nearly $400,000 in War Bond purchases to their credit, the employees can now boast that the slogan that started a seven months' campaign back in April, to buy a flying fortress, was no idle boast. Give they did, and the satisfaction is theirs of feeling that sometime soon their money will be symbolized in those glorious metal battleships of the air over Berlin or Tokyo!

At the institution of J.J. McIntire and H.W. Tutchings, the campaign was started under the direction of W.H. Evans, with a program in cafeteria NO. 1, toward the end of March. Talks were given by former commanding officer, J.F. Rodenhauser and Works Manager, E.L. Nellis. The Sandusky High School band came to Plum Brook to furnish excellent music. One of the first to sign up was police supervisor, J.E. Hess. The men in the manufacturing area got busy with general plant superintendent T.L. O'Shea and his assistant, W.J. Hulings cooperating to produce results quickly.

At times, the campaign to get everyone signed up for purchases lagged and there was discouragement. But, the bond department, under the persistent and able direction of Robert Hohly, surrounded by the following determined aids, Emma Weidel, Gertrude McManus, Georgia Walley, Stanley Rinkenbach, I.H. Kahle, Leonard Osberg Harold Jones, Wick Beckham, Horace Platt and Eugene Likes. Gaylord Heath of Payroll and Nelson Rupp of Industrial Relations also did yeoman work.

So, the campaign that started with a picture of a flying fortress on placards posted throughout the reservation has now ended in an actuality and Plum Brook can truthfully say

CHARLES E. FROHMAN

"Trojan Triumphs!"

The estimated cost of a flying fortress is $35,000. War Bond purchases at Plum Brook as of yesterday were $396,420 approximately. This means nearly $50,000 as a start for the purchase of another fortress and another occasion for legitimate boasting. And the boast is, that before much rice is consumed by the 'little yellow men or many inches of wienerschnitzel (ersatz at that) is taken down the gullets of the boys who live in the land of the Wilhemstrasse, we'll be giving our boys another battleship of the air to soar over and gear bamboo Tokyo and boulevarded Berlin.

Police Get Indian Fielder

The ranks of the police force have been augmented by the appearance of "Hank" Edwards, centerfielder for the Cleveland Indians. Edwards, a Norwalkian, was a sandlot favorite in these parts and eventually attracted enough attention to land with the Baltimore Orioles, the farm aggregation for the Indians. Toward the end of last season Hank was brought to Cleveland and did a swell job. His batting average was .287. With the Orioles he hit 20 home runs.

Plum Brook Ordnance Works
Sandusky, Ohio

Gentlemen:

To "Buy a Bomber" seemed such a practical thing to do when it was announced a number of months ago, and it is good to realize that with their subscriptions for War Savings Bonds exceeding $396,000.00, the employees at Plum Brook have actually made a contribution to the war effort by buying a mighty "Flying Fortress".

I want to congratulate the people at Plum Brook, and I know that it is - just the beginning!

Very truly yours,

Charles E. Frohman
Erie County Chairman
War Savings Committee

CEF:kg

BY DIRECT WIRE FROM

CLASS OF SERVICE

This is a fullrate Telegram or Cableram unless its deferred character is indicated by a suitable symbol above or preceding the address.

WESTERN UNION

NEWCOMB CARLTON, PRESIDENT J. C. WILLEVER, FIRST VICE-PRESIDENT

1223

SIGNS

DL = Day Letter
NM = Night Message
NL = Night Letter
LCO = Deferred Cable
NLT = Cable Night Letter
WLT = Week-End Letter

The time shown in the date line on full-rate telegrams and day letters, and the time of receipt at destination on all messages, is STANDARD TIME.

W'10 214/211 GOVT DL 1 EXTRA CLEVELAND OHIO 18 330P

PLUM BROOK ORDNANCE WORKS

SANDUSKY, OHIO

THE SECRETARY OF THE TREASURY, THE HONORABLE HENRY MORGENTHAU, JR. WISHES US TO EXPRESS TO THE PLUM BROOK ORD. WKS. EMPLOYEES HEARTFELT THANKS FOR THEIR SPLENDID SUPPORT OF THE WAR BOND PROGRAM WHICH WE UNDERSTAND CAN NOW BE MEASURED IN TERMS OF TOTAL SUBSCRIPTIONS OF MORE THAN $396,000 OR AN AMOUNT SUFFICIENT TO PURCHASE A FLYING FORTRESS. THIS IS A MOST COMMENDABLE ACCOMPLISHMENT AND WE SINCERELY HOPE EACH AND EVERY PURCHASER OF THESE BONDS WILL GAIN THE FULL SATISFACTION OF KNOWING THAT THEY HAVE MADE A WORTHWHILE CONTRIBUTION TO THE NATION'S WAR EFFORT IN ADDITION TO ENLISTING THEIR DOLLARS IN THE SAFEST POSSIBLE WAY IN THE WORLD TODAY FOR PROFIT. WHILE WE DO NOT HAVE YOUR LATEST FIGURES ON HAND, WE SINCERELY HOPE THAT WE MAY OFFER FURTHER CONGRATULATIONS IN THE VERY NEAR FUTURE UPON YOUR REACHING THE GOAL SET BY THE GOVERNMENT OF 10 PERCENT OR MORE OF TOTAL PAYROLL BEING ALLOTTED TO BOND BUYING. MAY WE URGE YOU TO EXERT EVERY EFFORT TO THE END THAT THIS GOAL MAY BECOME AN ACCOMPLISHED FACT FOR OHIO IN ADVANCE OF THE ANNIVERSARY HOUR OF PEARL HARBOR MONDAY, DECEMBER 7TH. WE SHOULD ALSO LIKE TO ADD SINCERE THANKS OF THE TREASURY DEPARTMENT AND THE WAR SAVINGS STAFF FOR OHIO FOR YOUR GOOD EFFORTS.

HAROLD H BREDLOW EXECUTIVE SECRETARY WAR SAVINGS STAFF FOR OHIO.

Image 14: The Plum Brook Ordnance Works (PBOW) News was published every Saturday for the duration of the war. It emphasized exemplary work habits and kept employees up to date on the social comings and goings. Plum Brook employees ranged from sixteen to eighty years old and came from all around the country. They were tied together by a common sense of purpose to assist the Allied victory. There were also social events, sports teams, and holiday functions that created a strong and closely knit culture. Courtesy of Milan Public Library.

Image 15: Abbott & Costello appeared at the Plum Brook Ordnance Works in August 1942 to encourage workers to buy war bonds. Other campaigns included the display of a captured Japanese submarine, a visit by General MacArthur's ranger troop, and several all-Plum Brook days at Cedar Point, an amusement park in Sandusky. (Permission courtesy of the Charles E. Frohman Collection at the Rutherford B. Hayes Presidential Center, Freemont, Ohio)

In August 1942 the film and comedy duo Abbott & Costello visited Plum Brook to encourage the workers to purchase even more war bonds. The pair entertained the audience on a stage erected behind the administration building. After making jokes and imitating the sound of steam engines, Costello became serious and shouted, "We're going to put the three louses, Hitler, Hirohito, and Mussolini, in their place. We're going to send them right to a good seat—the hot seat!"[10] They spent the remainder of the day at Cedar Point, a local amusement park. Seven months later the bond campaign came to a successful conclusion with most employees setting aside 10 percent of their total salary for bond purchases.

It was difficult to keep morale strong. The labor was demanding and the conditions were harsh. Because buildings were considered temporary, they lacked adequate insulation from the cold Ohio winters. In December 1942 nearly all of the employees worked in their heaviest coats and hats as "icy blasts tore through warped window casings."[11] Most people pulled down their office shades in hopes of deflecting the cold winds. Typewriters became sluggish, and the secretaries forced their numb fingers to press the frozen keys. It was not unusual for twenty-foot icicles to form on the 110-foot-tall water tower. One office manager said that he spent most of the day brushing snow off his desk. Many of the employees rode bicycles to

Image 16: A typical Plum Brook Ordnance Works office building. Rooms like this looked relatively warm and comfortable, but their functional military construction left occupants vulnerable to the Ohio winter weather. Courtesy of Corps of Engineers, U.S. Army. (No. 21747, 1944)

work because of conservation efforts, which also proved to be quite challenging in the winter. While the conditions were difficult, employees endured them, knowing that loved ones were probably risking their lives in far more dangerous and demanding situations abroad.

Plum Brook emphasized safety and conservation. Supervisors had regular safety dinners where they discussed concerns or problems that they thought might threaten their workers. Plum Brook employees were also subject to strict conservation and rationing for the war. They saved gas by carpooling or biking to work. Many families planted "victory gardens" around their houses to help supply their own food needs.

As was typical in most industry during the war, women represented a large proportion of the workforce at Plum Brook.[12] Women held jobs as nitrator operators, wash-house helpers, packers, box factory operators, truck drivers, and clerical workers. There were numerous stories of patriotic women working for the war effort. For example, June Franklin's job was to nail the wooden bottoms onto TNT boxes. She had fourteen close relatives fighting in the war, and when she learned that her husband had been wounded in action in North Africa, she immediately walked into the Plum Brook payroll office, bought a war bond, and signed her name to the bottom of a TNT box. She vowed never to miss a minute of work and said, "Every time I drive a nail into the bottom of a TNT box I feel that I'm driving a nail into the Axis coffin."[13]

In 1945, World War II came to an end. In early May, Germany surrendered, and three months later, after the devastating atomic bomb attacks, Japan surrendered. President Harry Truman announced

Image 17: A drawing from the Plum Brook Ordnance News reminding women of the proper placement of their identification badges. Courtesy of Milan Public Library.

that the war was over via a radio broadcast that night, and proclaimed the next two days as a national holiday. Simultaneous celebrations spontaneously erupted through the United States. In nearby Akron, Ohio, nearly the entire city celebrated on Main Street, which was filled with "people yelling and hugging each other and mothers of G.I.s crying."[14] At Plum Brook the celebrations were more muted. One observer said, "There was quiet elation of course, and here and there especially among female employees there were misty eyes and tears of happiness because their loved ones were safe at last."[15]

After the Japanese surrender, the production at Plum Brook came to an end. For three-and-a-half years it had operated twenty-four hours a day, seven days a week, with only a few work stoppages.

Image 18: This poster was issued by the Women's Bureau to help ensure that women workers did all they could to remain healthy and safe while on the job. (National Archives and Records Administration. NWDNS–44–PA–946)

Image 19: Employees at Oak Ridge National Laboratory celebrating the end of World War II. Spontaneous celebrations erupted all over the country when Japan surrendered. (1945) (Department of Energy Photo 946-26)

Eighteen million hours of labor had produced nearly one billion pounds of explosives, with no fatalities. Several months were needed to close and "decontaminate" the facility, so that the entire site could be returned to the government.[16] Suddenly, Plum Brook was silent again. Some observed a return to nature as they left the plant for the last time. For four years, since ground was first broken, peace and quiet had been absent from these lands. Now there was a "gloriously blue sky overhead" and sounds of "what seemed like a thousand birds throating a medley of songs just as if the feathered songsters knew that peace had come at last to the world of men."[17]

As Plum Brook went quiet, the nation began to wrestle with the realities of the new atomic age. The war ended with the detonation of an atomic bomb, but could the technology that enabled this deadly device be used for other applications? This quest became the goal for scientists working at an increasing number of research and test reactors built throughout the United States.

Image 20: Workers dig up transit lines, flumes, and buried TNT at Plum Brook. The explosive remains were then detonated safely elsewhere. Despite claims that there would be no long-term damage to the land, by 1948 it became evident that the Plum Brook site had suffered considerable contamination. During the early 1950s the land became a subsidiary of the nearby Ravenna Arsenal and was subjected to even more contamination. The NACA attempted to clean up the area in the mid-fifties. The United States Army Corps of Engineers is still working on the project today. (1956) (NASA C–2003–826)

The Dream of a Flying Reactor

After World War II, the United States military began envisioning ways to take advantage of nuclear technology for its weapons arsenal. Since the Army had already developed an atomic bomb, it hurriedly began working on even more destructive applications, namely, a nuclear warhead for a missile, while the Navy successfully built the USS Nautilus, a nuclear-powered submarine. The Air Force began its nuclear initiative on 10 October 1945, when J. Carlton Ward, Jr., president of Fairchild Engine and Airplane Corporation, testified before Congress on behalf of the post-war aviation industry. He claimed that the nation that first developed an atomic airplane would have an unparalleled tactical advantage in future conflicts.[18] Thus was born a fifteen-year, billion-dollar quest to put a nuclear reactor into an airplane for use as a fuel source. The apparent benefits appeared well worth the risk. Some believed that nuclear airplanes would be able to fly for months without the need to refuel. With the heightening tension of the Cold War and the increasing rumors that the Soviets were close to developing their own nuclear airplane, the American government quickly launched a massive effort to close the perceived gap.

A great number of technical problems needed to be solved.[19] For example, the crew would have to be shielded from the onboard reactor for obvious safety reasons. Traditional shielding was so thick and heavy that it would significantly complicate liftoff. Another safety problem was the danger to people on the ground. Should the plane crash, many observers thought that the effect would be similar to the detonation of a hydrogen bomb. Others in the nuclear field tried to reassure the skeptics that these predicted dangers were unrealistic. Lesser concerns consisted of finding materials that could withstand the high operating temperatures of the reactor.[20] Despite the controversy, Pratt & Whitney, Convair, the U.S. Air Force, Lockheed, and General Electric all began developing reactor testing technologies to try to solve the myriad technical problems associated with the nuclear airplane.

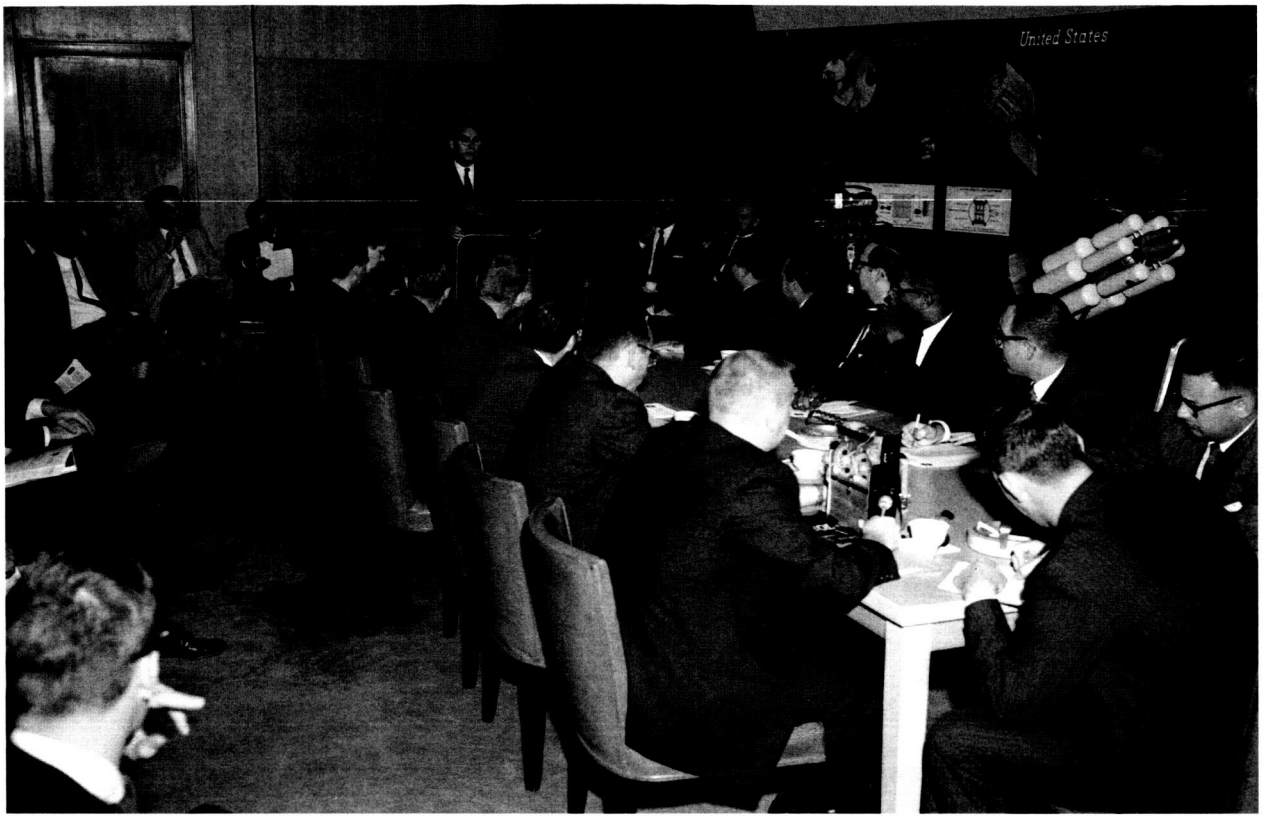


Image 21: Abe Silverstein, director of Lewis Research Center, addresses an audience about the benefits of nuclear propulsion. In the background is a display titled "Nuclear Energy Research Technology" that features images of nuclear rockets and uses for thermoelectric power. (1961) (NASA C-1961-58359)

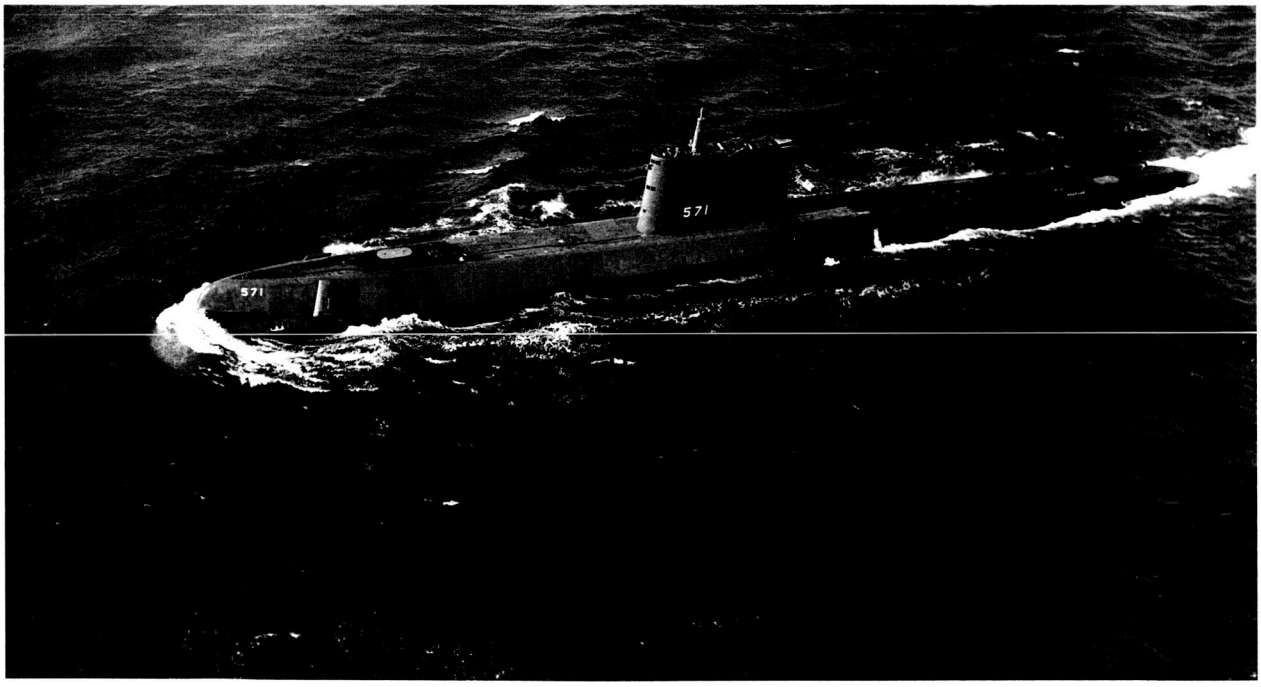


Image 22: Launched on 21 January 1954, the USS Nautilus was the world's first nuclear submarine. The nuclear engine enabled the craft to remain submerged for weeks. After its success, the U.S. government became interested in constructing atomic-powered airplanes, which, it hoped, would have the potential to remain in flight for weeks without refueling. (National Archives and Records Administration, NWDNS-80-G-709366)

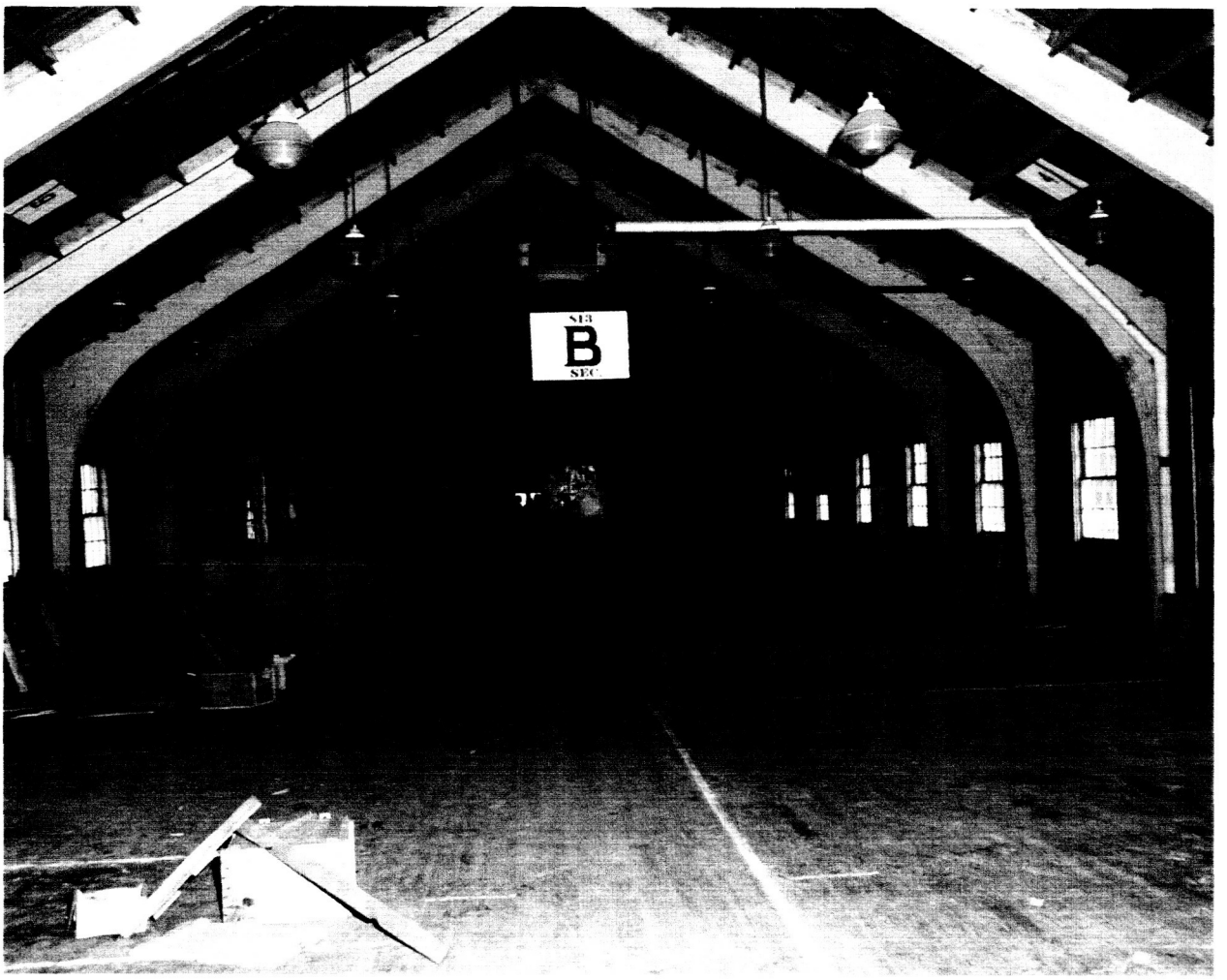


Image 23: NACA officials inspect Plum Brook Ordnance Works buildings to determine if they could be used for the NACAs purposes. When the inspectors opened up many of the buildings, they found rooms with calendars, coffee mugs, and papers as they had been left the day the Ordnance Works closed down. An eerily similar scene would be encountered forty years later by the decommissioning team in the Plum Brook Reactor Facility. (1958) (NASA C-1958-47291)

In 1951, the NACA began to explore the possibility of developing its own nuclear reactor to assist in the development of the nuclear airplane. The NACA was uniquely qualified to take the lead in the endeavor because of its expertise as an aeronautics laboratory. This government agency was also important because it willingly shouldered the risks associated with creating innovations. Virginia Dawson wrote, "By assuming the costs of research and testing, the government could pursue promising new technology, regardless of blind alleys and false starts."[21] The NACA selected the Lewis Flight Propulsion Laboratory in Cleveland, Ohio, to design and build the reactor. Representatives from the laboratory examined nineteen sites in Ohio and Pennsylvania for the reactor facility. The sites were judged with a predetermined list of criteria based on safety, cost, and accessibility. Lewis representatives finally chose the Plum Brook Ordnance Works because it was near to Cleveland and already had much of the infrastructure required to operate a nuclear reactor.[22]

Not just at Plum Brook, but throughout the United States, the government took the lead in developing test reactors. These projects exemplified the "big science" era. Big science was a new trend in research characterized by expensive programs massively funded by external agencies and patterned after the Manhattan Project.[23] The government made big science possible through its willingness to spend large amounts of money to develop projects whose outcomes were unknown. This activity took place at national laboratories like

Primary Document #2

The following document is an excerpt from a report that selected Plum Brook as the ideal site to construct the NACA test reactor.

SITE SURVEY FOR NACA RESEARCH REACTOR
September 13, 1955
Prepared for NACA by the Nuclear Development Corporation of America
White Plains, New York

This report summarizes the studies and evaluation of nineteen sites considered for location of a high-flux nuclear research reactor facility which is being designed by the Lewis Flight Propulsion Laboratory of the National Advisory Committee for Aeronautics. The research facility is to be used primarily for engineering studies and performance test evaluation of aircraft reactor power plant systems and components...simulating actual operating conditions.

The location of nineteen possible sites which have been considered includes: Altoona, Pennsylvania; Ashtabula, Ohio; Confluence, Pennsylvania; Cumberland, Maryland; DuBois, Pennsylvania; Fairport, Ohio; Indiana, Pennsylvania; Johnson Island, Ohio; Kittanning, Pennsylvania; Lorain, Ohio; Perrysville, Ohio; Plum Brook Arsenal; Portage, Pennsylvania; Ravenna Arsenal; Saxton, Pennsylvania; Seward, Pennsylvania; Strongsville, Ohio; Susquehanna Ordnance Depot; Twinsburg, Ohio.

It is concluded, as a result of this survey, that the most desirable site is in Plum Brook Arsenal, which is located in a sparsely populated area three and one-half miles south of Sandusky, Ohio. From a technical standpoint, this is among the best of the sites surveyed. Its favorable safety characteristics are inherited directly from the Arsenal's own requirements for both intra- and extra-site safety. Site development costs and the cost of maintaining security should be a minimum, since it is an active Government-owned facility with security fences and patrols, roads, and other services already established. The proximity to the Lewis Flight Propulsion Laboratory (fifty miles, one hour travel by car) will permit full utilization of the administrative and technical personnel and the extensive facilities of the Laboratory. This situation should contribute greatly to the reduction of the cost of establishing and operating the facility.

NDA Plum Brook Nasa Nuclear Research Facility 1955

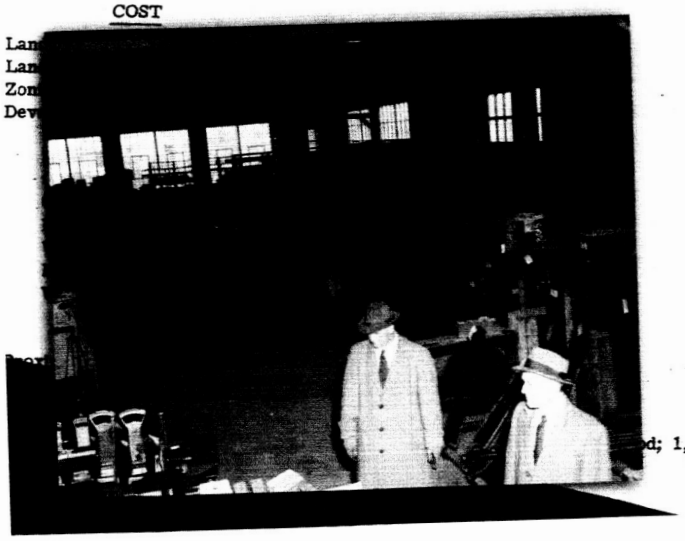
SITE SURVEY FOR

NACA RESEARCH REACTOR

September 13, 1955

SITE EVALUATION CHART

	Weighting Factor	Indiana, Pa.	Johnson Island, Ohio	Kittanning, Pa.	Lorain, Ohio	Perrysville, Ohio	Plum Brook Arsenal
SAFETY							
Good Waste Disposal Possibilities - Air	4	8	8	8	4	8	8
Good Waste Disposal Possibilities - Water	4	4	8	0	4	4	4
Isolated From High Population Density	4	8	4	8	8	8	8
Closeness to Disaster Control Agencies							
Fire Department	3	3	0	0	3	0	6
Hospital	2	4	2	4	2	2	2
Police or Military	2	2	0	2	2	0	4
Protection From Sabotage	2	2	2	2	2	2	4
Dependable Services							
Electricity	3	6	3	6	6	3	6
Water	4	4	8	4	8	4	12
Communications	2	4	0	2	4	2	4
Good Roads	2	4	2	2	4	2	4
Large Area	4	4	8	4	4	8	8
COST							
Lan			0	2	1	1	3
Lan			1	2	1	2	2
Zon			1	2	2	2	2
Dev							
			1	1	2	1	2
			0	0	2	0	3
			2	0	2	2	2
			2	2	2	2	1
			2	2	2	1	1
			1	2	1	1	3
			2	0	1	1	2
			2	2	1	2	1
			2	0	6	2	6
			3	0	9	3	9
			64	57	83	63	107



d; 1, Fair; 0, Poor]

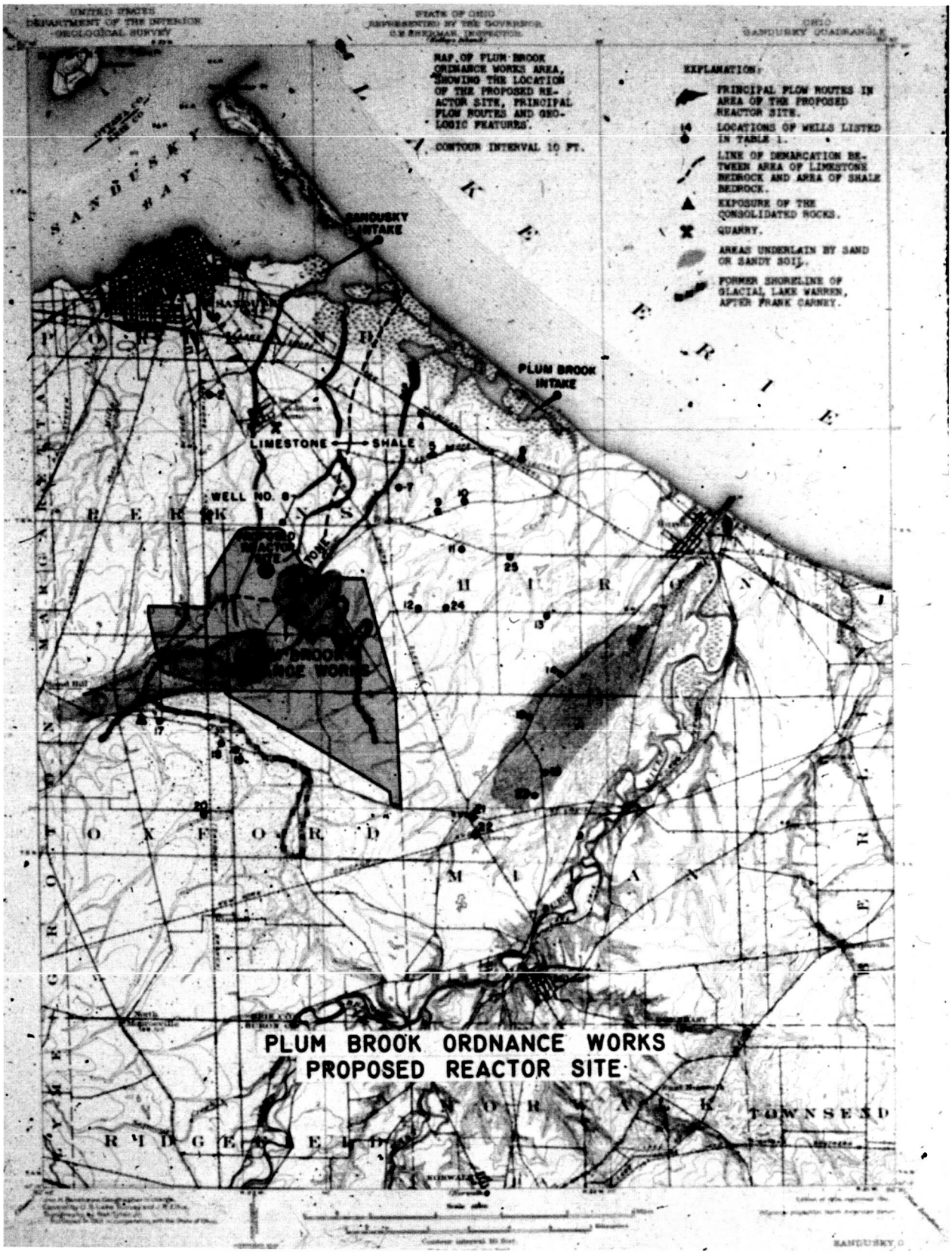
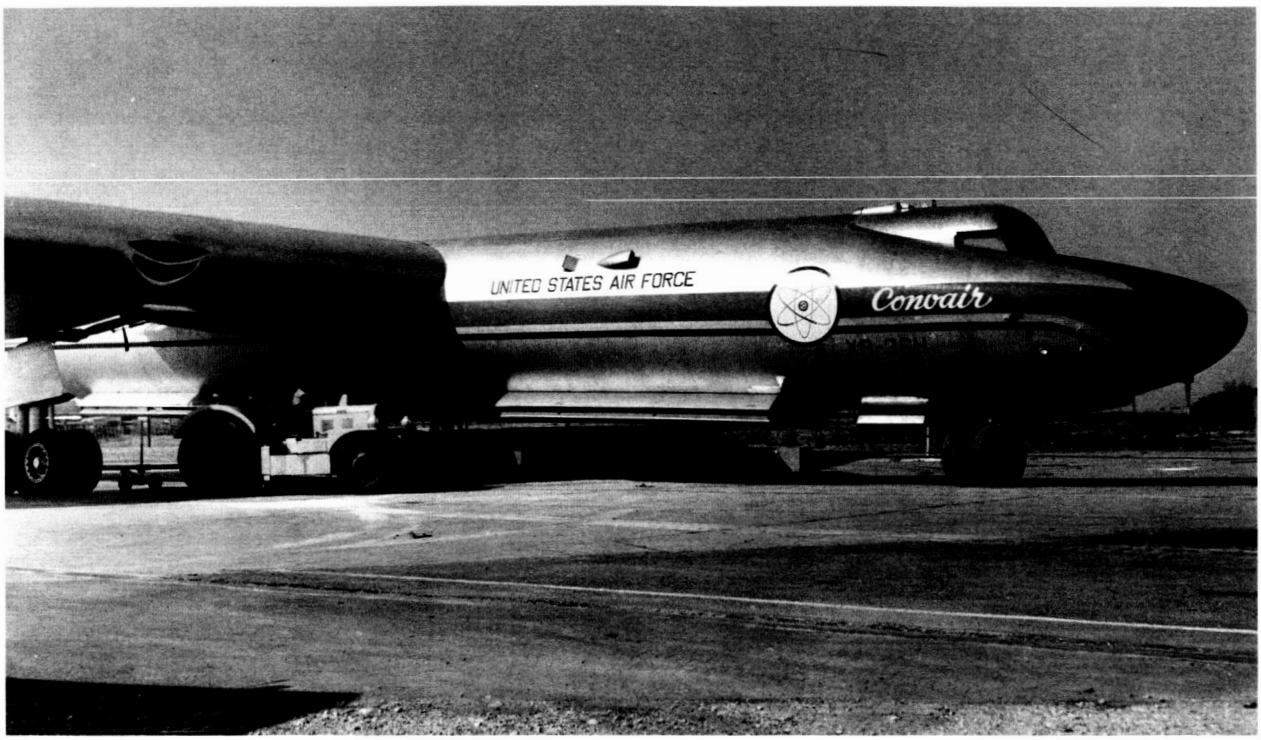


Image 24: This map shows Plum Brook's location relative to Lake Erie and several Northern Ohio cities. Plum Brook's only disadvantage was the relatively large population in nearby Sandusky. However, it was decided that any experiment deemed too risky would be sent to more remote test reactors in Idaho Falls like the Materials Test Reactor or the Engineering Test Reactor. (NASA CS–12374B)

Image 25: Argonne National Laboratory-West. Argonne's western site opened on 18 February 1949 in Idaho to serve as a testing ground for different types of reactors. Similarly to NASA Lewis and Plum Brook Station, Argonne's basic research was conducted at the main laboratory near Chicago, and nuclear facility testing and development was performed at the Idaho site. In December 1951, the Experimental Breeder Reactor I (EBR-1), the world's first nuclear power plant, produced the world's first nuclear-derived electricity. Other Argonne facilities included the Materials Test Reactor (1952–1970), the Engineering Test Reactor (1957–1982), and the Advanced Test Reactor (1967–present). (Department of Energy Photo 2001951)

Argonne, Oak Ridge, Brookhaven, and Los Alamos. Nuclear research was given a high priority, and these laboratories took the lead in developing test reactors. Between 1942 (when the first research reactor was built) and 1962 (when Plum Brook was in operation), the government constructed seventy-seven research and test reactors.

There were two other reasons why the U.S. government led the exploration into nuclear research. The first was secrecy. While much of the research generated at governmental facilities was eventually declassified for transfer to industry, as it was being produced it remained classified. The restricted environment of the typical government laboratory was essential when research was directly tied to national security issues. Second, national laboratories had the luxury of assembling a wide variety of specialists who could be brought together for a common goal. The prime example of this was the Manhattan Project's grouping of talent to achieve a vast, complex, yet single-minded goal that would have been far beyond the capabilities of any university laboratory or corporation. Since these specialists were all under the control of a single entity, such as the Atomic Energy Commission (AEC), their focus could be redirected at the government's discretion.



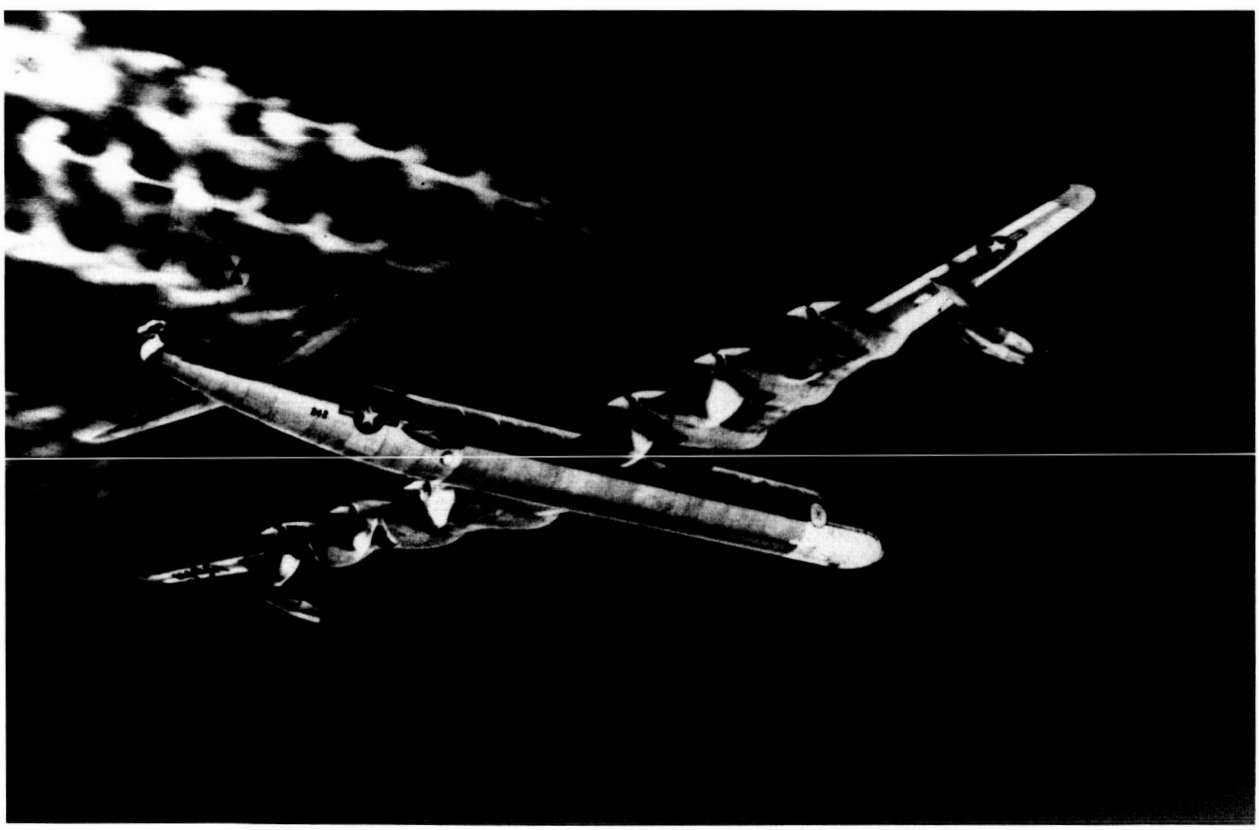


Image 26: The aircraft in these photos, a B-36 bomber converted to run a nonpropulsive test reactor during flight, flew forty-seven times between 1955 and 1957 over Texas and New Mexico. A nuclear-powered airplane was never flown. Engineers were aware of the multiple problems associated with an atomic plane, but they remained excited about the long-term possibilities. (Department of Energy)

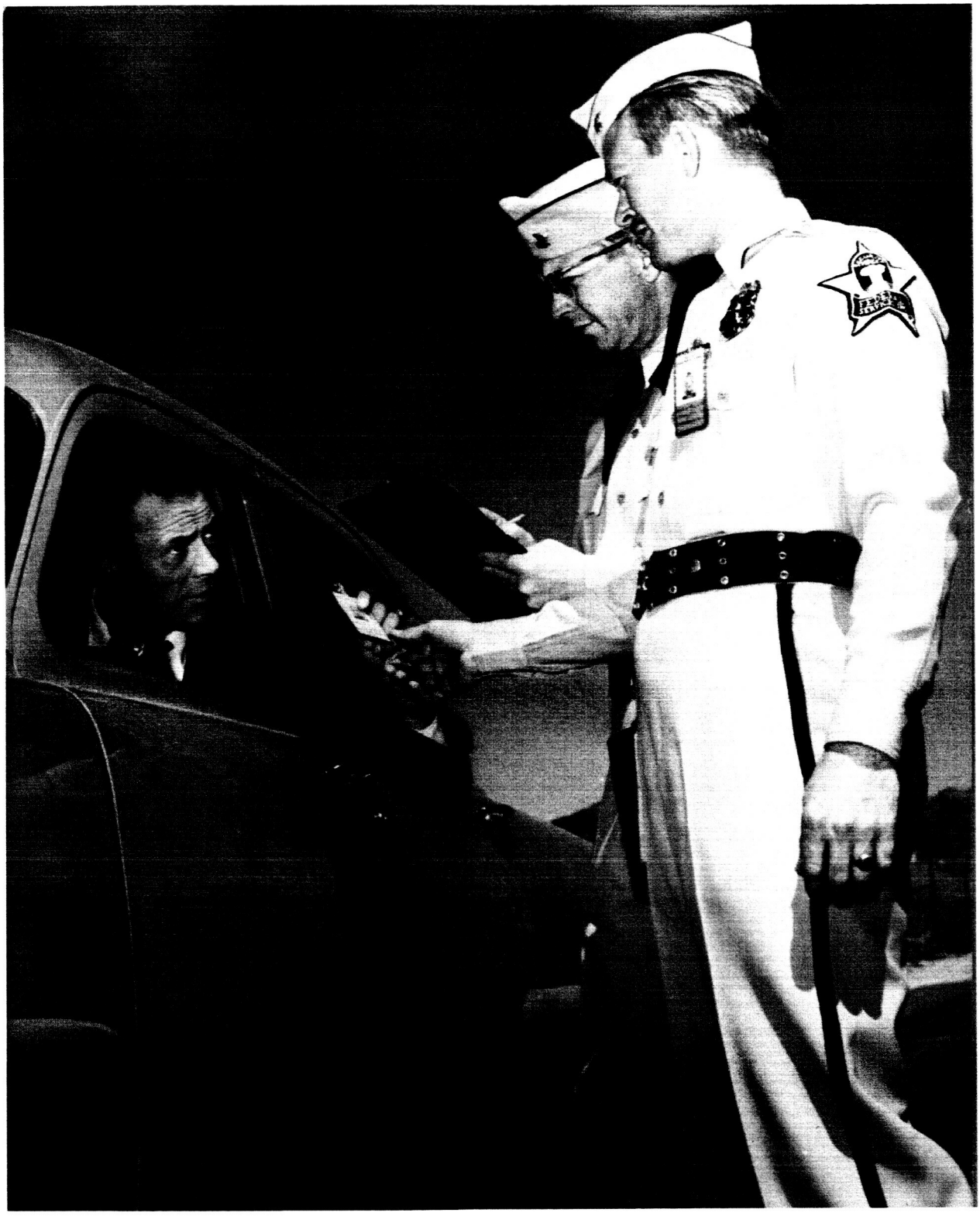


Image 27: Guards Milton Miller (left) and John Metcalf inspect the badge of Frank Waters of the Joint AEC Department of Defense (DOD) Information Office. Notice the mushroom cloud on the shoulder patch. Although the mission of the security forces has not changed over the last forty-two years, uniforms, communication equipment, and vehicles are substantially different. (1960s) (Department of Energy, Nevada Operations Office)

Designing the Plum Brook Reactor

Engineers already working at the Lewis laboratory were given the task of designing the reactor. Dr. Theodore "Ted" Hallman had a Ph.D. in nuclear engineering and was the first division chief of the Plum Brook reactor. He worked on the reactor design and managed the startup test programs at Plum Brook. Most of his colleagues had no background in the nuclear field and taught themselves by studying nuclear engineering textbooks from the library.[24] Sam Kaufman, an engineer, also worked with Hallman on the design, though he had little nuclear training. His right-hand man was Alan "Hap" Johnson, who eventually became the head of Plum Brook Station itself. These men also augmented their studies by visiting other test reactor facilities at Oak Ridge, Lockheed, and Idaho Falls. Through this process they were able to master the concepts and build a unique and powerful test reactor that had an unparalleled emphasis on experimental facilities. Abe Silverstein also established a nuclear training school at Lewis to provide broad training in nuclear applications. Though few of the high-level attendees actually went to work at Plum Brook, teachers like Jim Blue consulted during its development and operation.[25]

In the simplest terms, a nuclear reactor creates energy by literally splitting atoms, the basic building blocks of matter. Atoms were once thought to be indivisible, but in the twentieth century, scientists discovered that they could be artificially split or fissioned. Nuclear fission occurs when a neutron collides with the nucleus of an atom. Once this division occurs, the nucleus releases a large amount of kinetic energy, which is the source of the power found in atomic bombs and nuclear reactors. All nuclear reactors generate energy through this fission process.

At the center of both power and test reactors is the active core, which is where the nuclear fuel, or fissionable material, is located. It is here that the chain reaction occurs and all the energy is released.

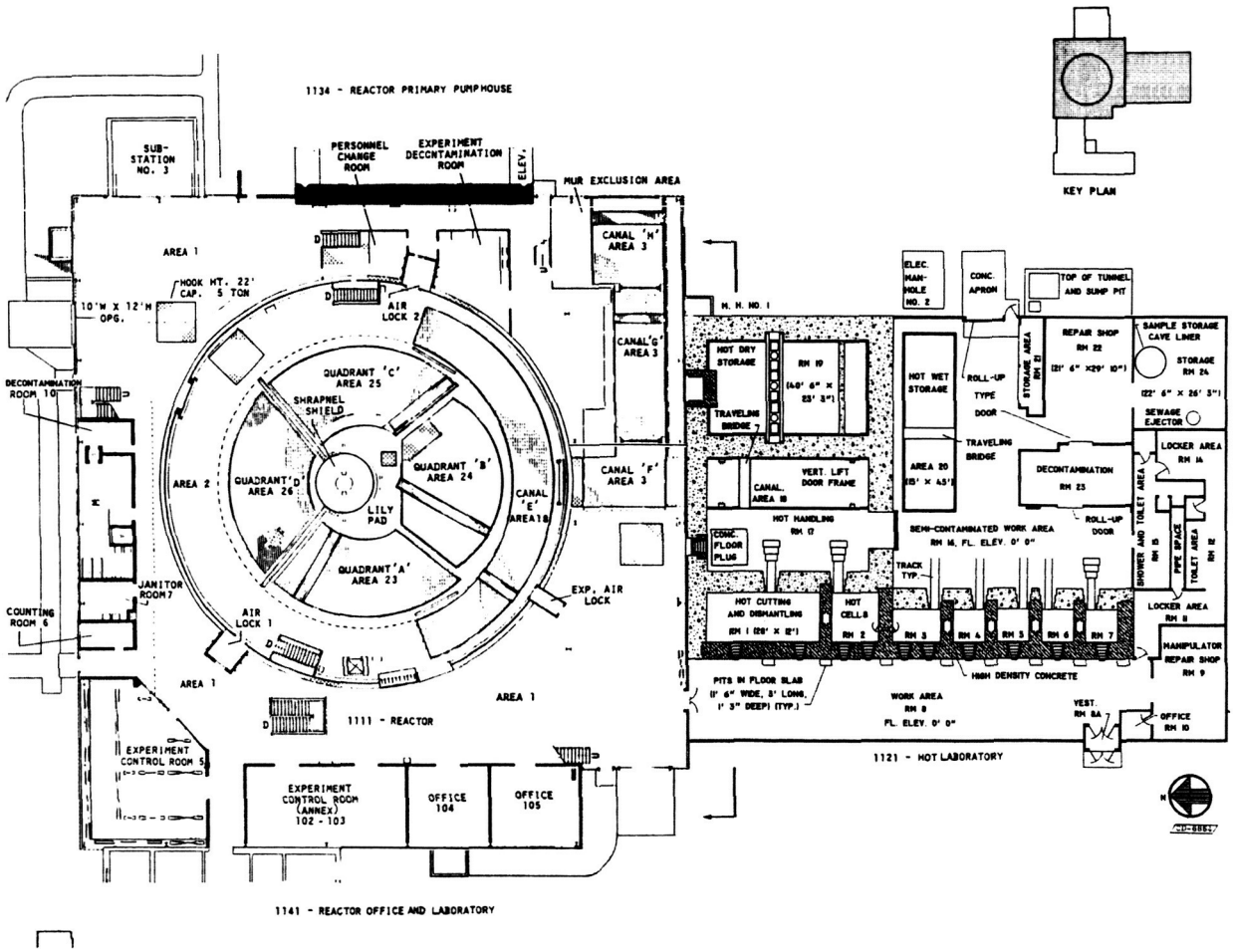


Image 28: First-level floor plan for the reactor building (no. 1111) at the Plum Brook Reactor Facility. (Plum Brook Reactor Facility Archives)

The fuel comes primarily from uranium isotopes, which are atoms that are chemically equivalent but different in mass. Uranium-235 is the principal isotope for the fission process; though uranium-238 is also present, it contributes very little to the process. The reactor becomes extremely hot during the chain reaction. A coolant mechanism is used, normally water, to carry away the heat. A reflector made of a material that prevents neutrons from leaving the pile surrounds the core. It gets its name from the fact that neutrons leaving the reactor core hit the reflector and are returned to the core. While the reflector can save a majority of these neutrons, some do escape and leak out of the pile. Shielding, usually constructed with steel, water, and concrete, is used to contain the radiation around the reactor core and protect people from the dangerous effects of radiation. The shielding materials effectively block the gamma, beta, and neutron radiation produced by the chain reaction. The shielding can also get very hot from the radiation (though much less so than the reactor), and the coolant helps to cool it as well. Reactor components called "moderators" enable scientists to control the speed of the neutrons so they will move at the proper velocity to split the nucleus. The moderator can be a solid, such as graphite, or a liquid, such as water.

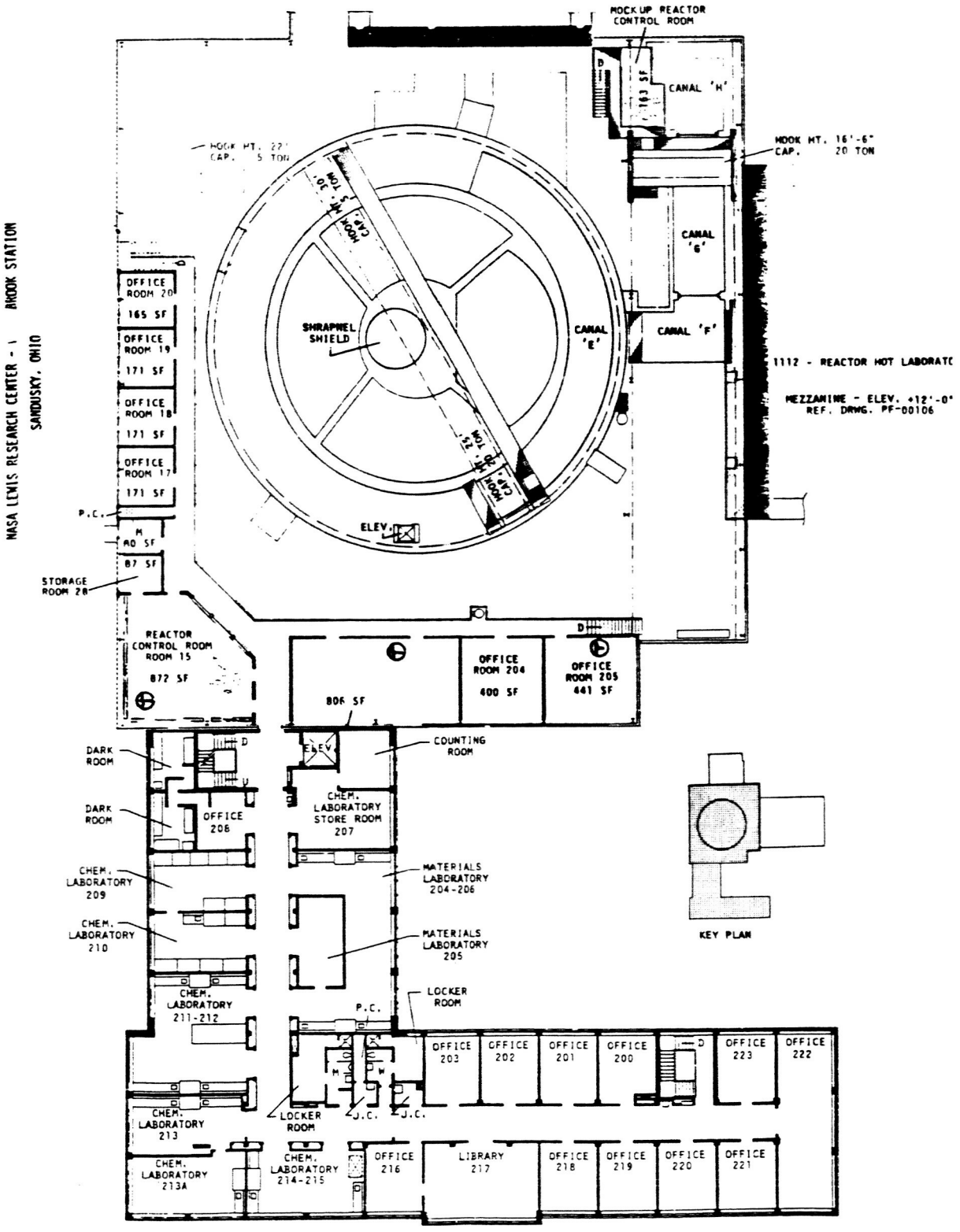


Image 29: First-level floor plan for the hot laboratory (no. 1112) at the Plum Brook Reactor Facility. (Plum Brook Reactor Facility Archives)

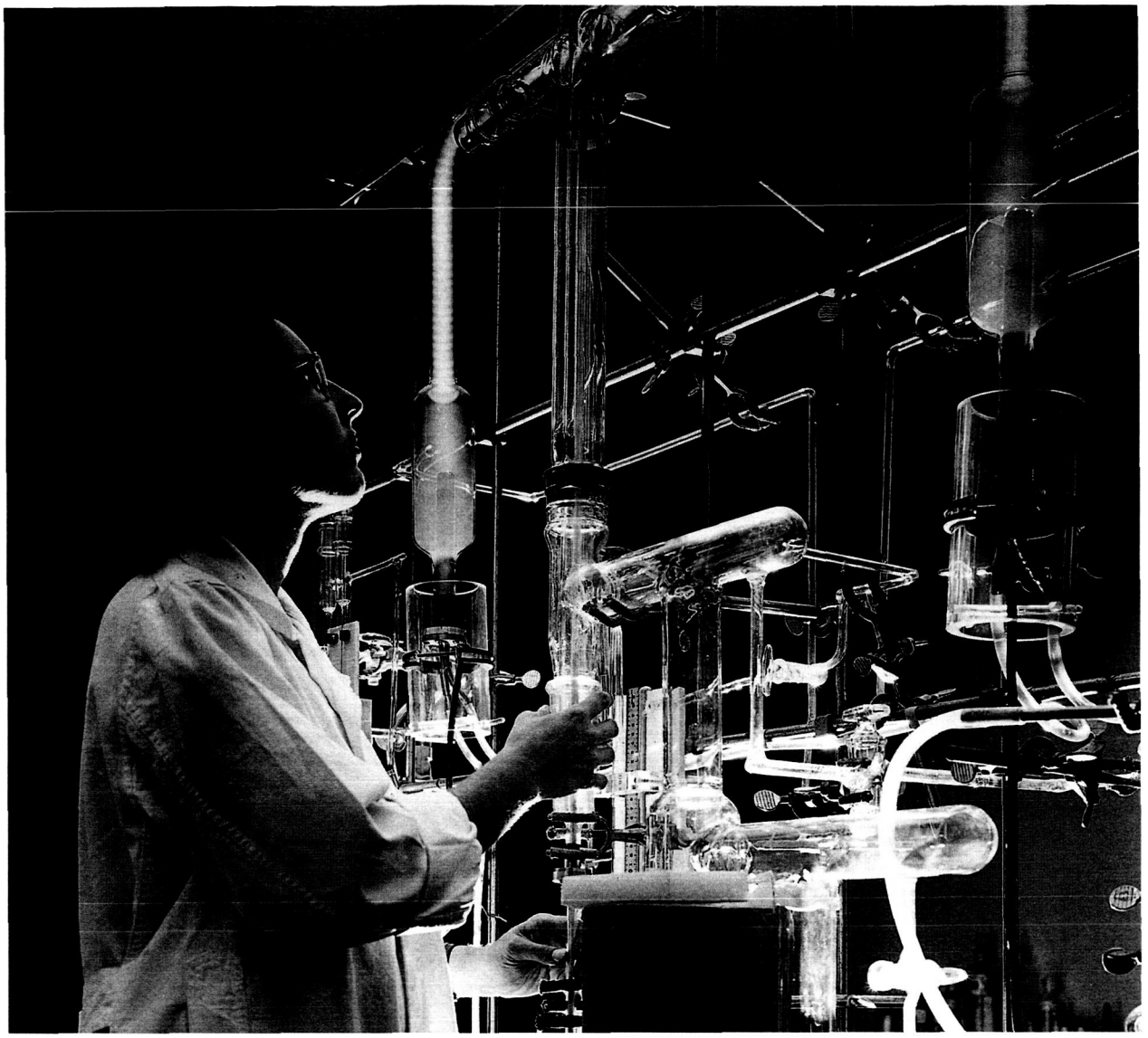


Image 30: One of the rare women physicists at NASA Lewis Research Center, working on an atomic laboratory experiment that pushed a gas at low pressure through a high-voltage discharge. (1957) (NASA C-1957-45726)

Another important part of the reactor are the control rods. If the reaction becomes unbalanced, with either too few or too many neutrons causing fission, then it could either die out or accelerate to dangerous proportions. Scientists use the control rods to regulate the process. These are usually made of boron or cadmium, elements that absorb the extra neutrons. Lowering or raising the rods into the core is a way of fine-tuning the reaction; the level of the rods controls the neutron absorption rate. The deeper they are in the core, the more neutrons are absorbed and the slower the reaction. The further they are pulled out, the more reactions take place.

There are three main types of nuclear reactors: power, research, and test. Research and test reactors as scientific tools are more common than most people realize. While power reactors frequently appear in newspaper headlines and are conspicuous because of their size and power, research reactors can be quietly tucked away, even in the midst of a college campus. Power reactors generate heat, which can easily be converted to other useable

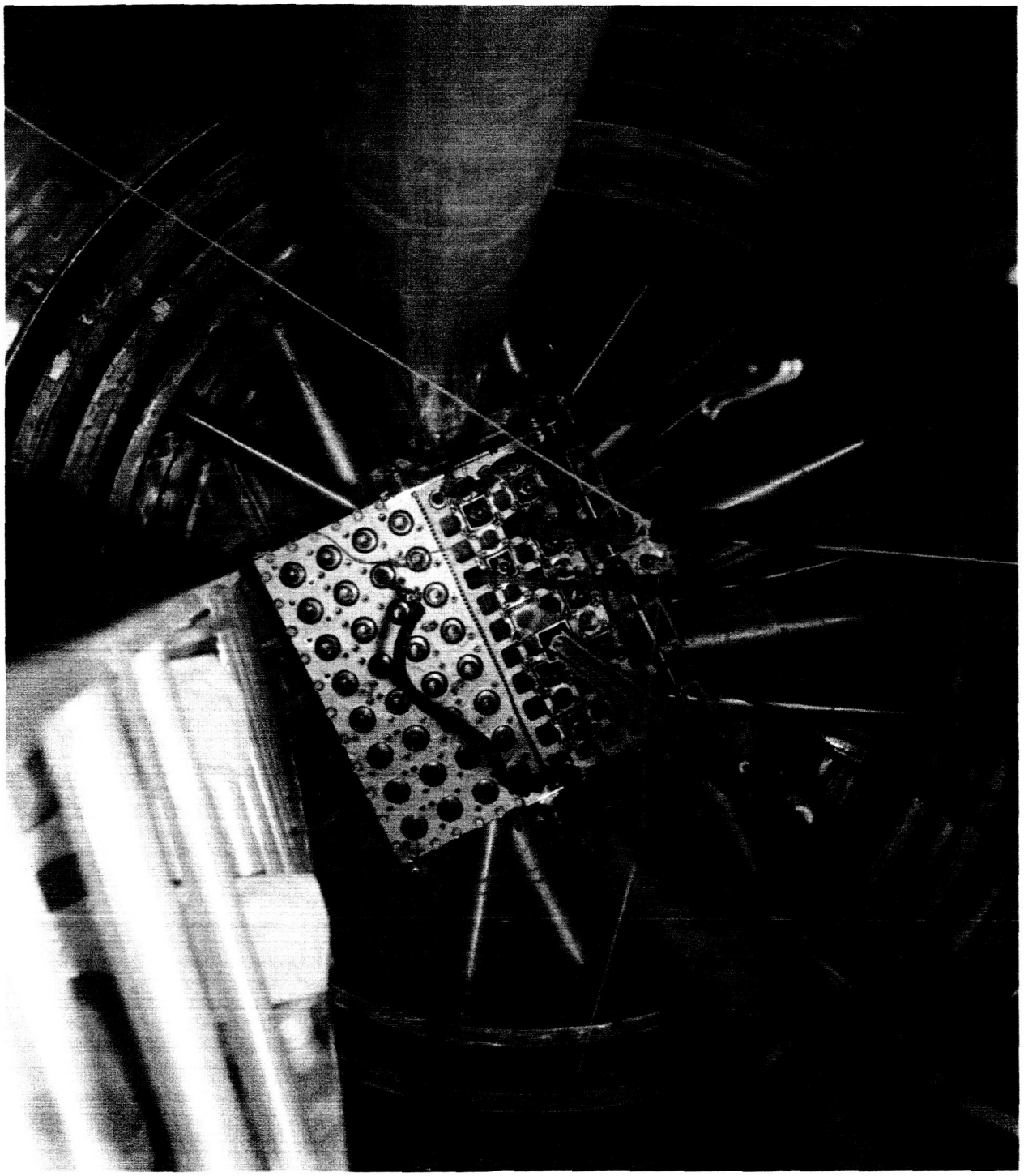


Image 31: The reactor core area from the top of the pressure tank. The reactor core (right side of the box) comprises a uranium-fueled section (a center array of three holes by nine holes for fuel control rods) surrounded by reflector material or experiments, to compose the complete four- by eleven-hole core array. The fueled core contains twenty-two stationary rods and five moveable cadmium and fuel control rods. The reflector material on three sides includes two cadmium and beryllium moveable regulating rods, three similar shim safety rods, and twelve fixed reflector plugs or experiments. The fueled core housing has reflector plates on the right and left sides and aluminum end-plates. Alongside the fueled section is a large four- by eight-hole reflector section (left side of the box), which provides facilities for inserting up to thirty-two experiments, one for each hole. The whole core structure sits on a stainless steel rack in the stainless-steel-lined pressure vessel (nine feet in diameter by thirty-one feet high). Three thermal shields are visible (the three rings) around the core. Two large vertical test holes run next to the ends of the core. One large tube runs through the large reflector section and another runs next to the fueled section. Three smaller beam tubes abut the right side of the core and three others are on the reflector side (left). (1961) (NASA C–1961–55533)

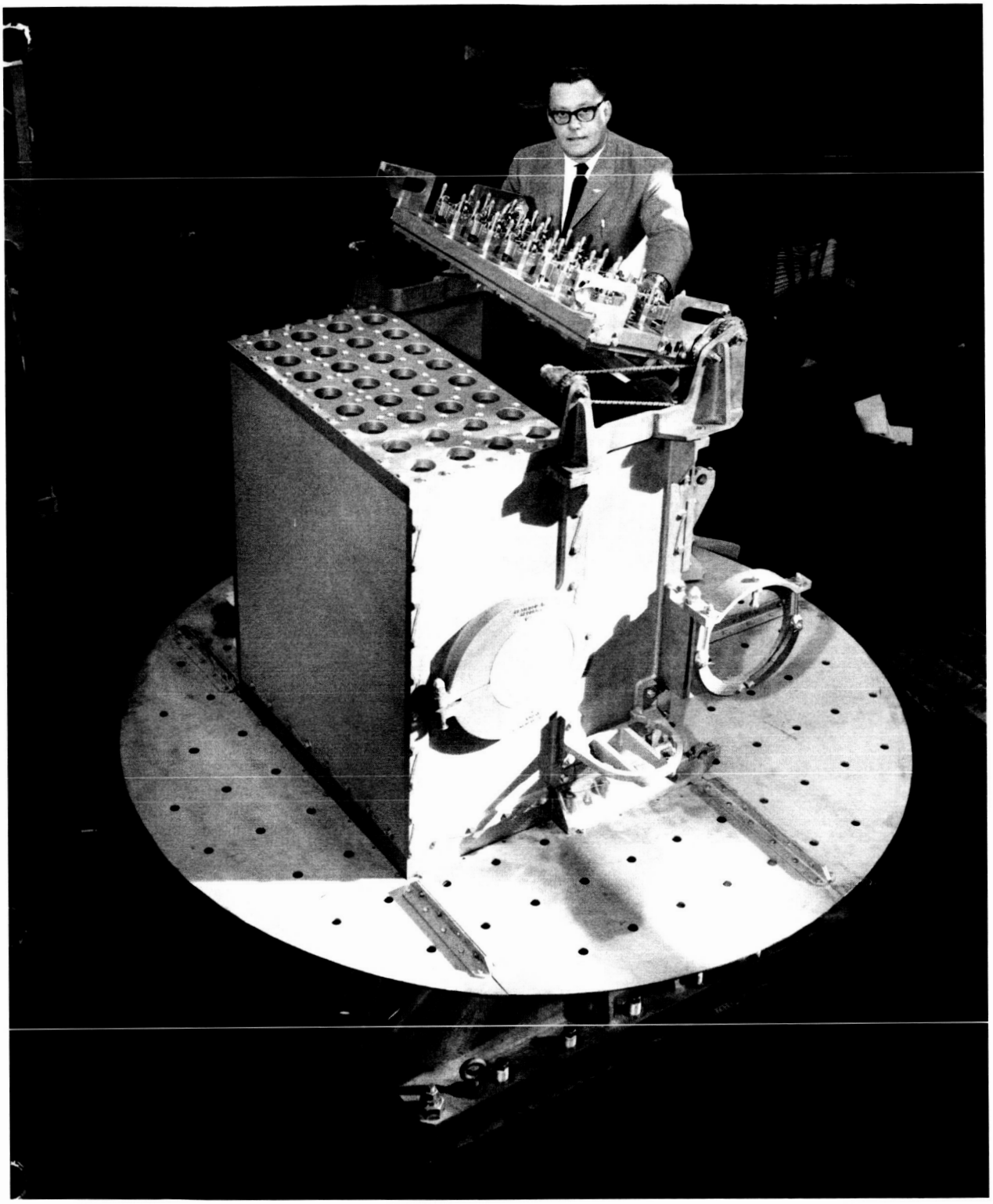


Image 32: The Plum Brook reactor's core, as demonstrated by the manufacturer prior to installation in the reactor pressure tank. (NASA C–2003–828)

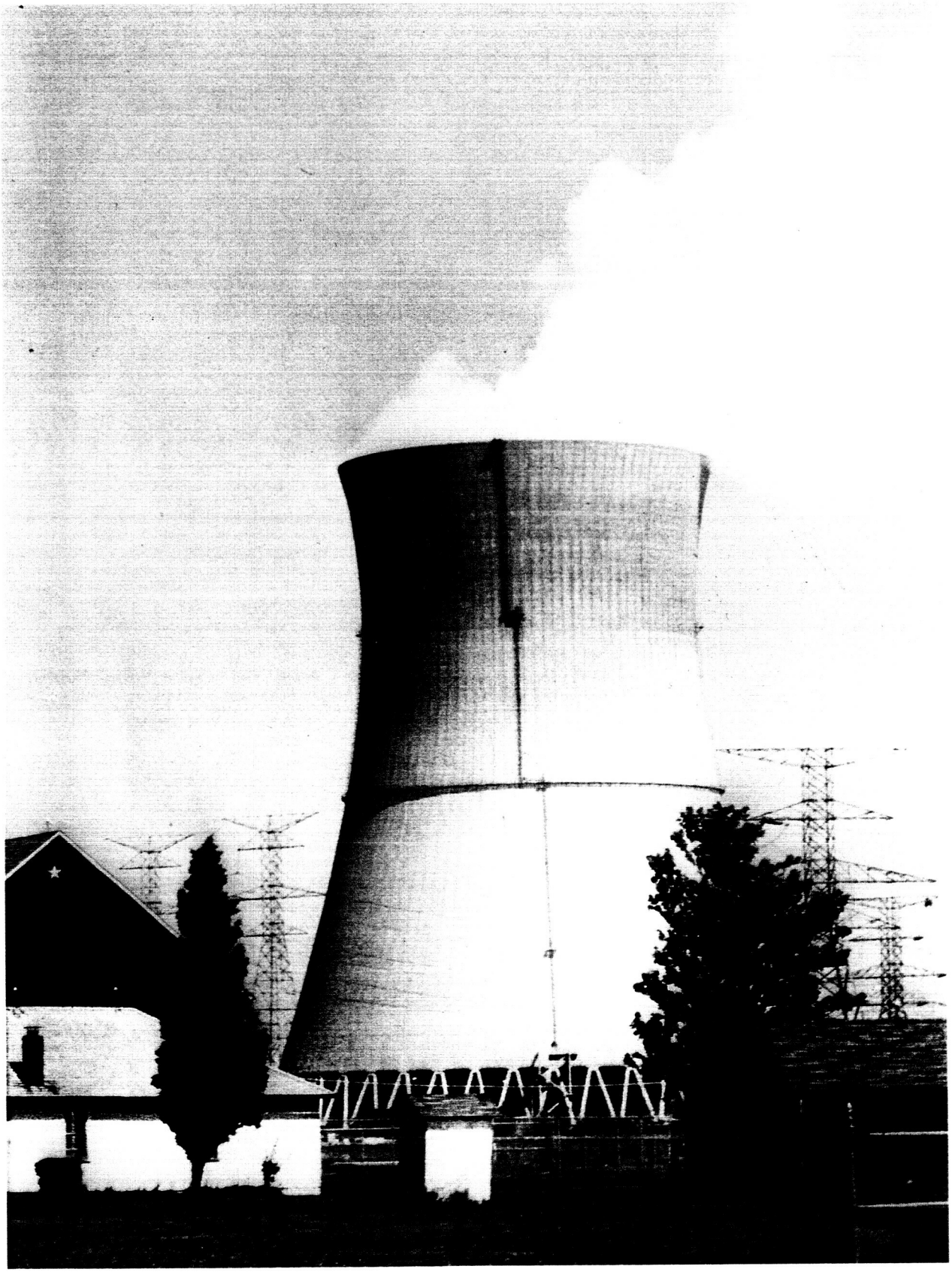


Image 33: Before construction began on the nearby Davis-Besse nuclear power reactor (pictured here), community leaders examined the safety of the Plum Brook facility for reassurances that a nuclear reactor could coexist within a populated area. (Cleveland Press Photo Collection—"Atomic Energy Facilities: Davis-Besse")

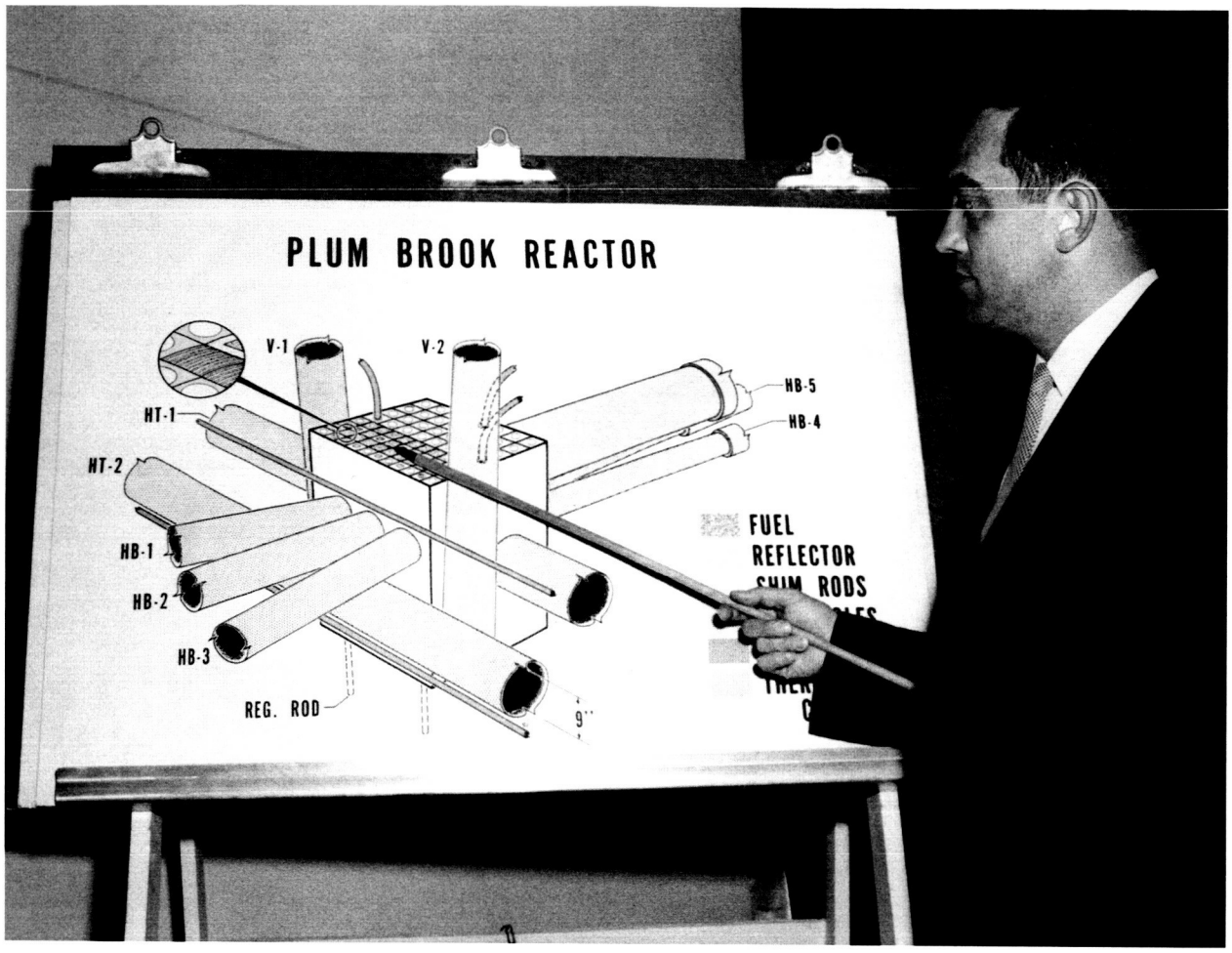


Image 34: A Plum Brook representative explains a diagram showing the main elements of the Plum Brook reactor core. The numerous test holes and rabbit tubes were what made the Plum Brook reactor unique. Few other test reactors in the United States had the ability to irradiate as many test materials simultaneously. (NASA C–2003–1039)

forms of energy, such as electricity. Research reactors operate at very low thermal power levels—so low, in fact, that they do not even require any type of forced cooling. They are used to measure nuclear parameters and other characteristics, which can then be used to build other reactors or to design experiments for test reactors. Test reactors are more powerful than research reactors and are able to produce much more intense radiation fields. Though they are still much less powerful than the power reactors, they generate enough heat to require a closed-loop forced-circulation coolant system. This system will remove the heat from the reactor by transferring it to a secondary cooling system, which releases it into the atmosphere through cooling towers.

Radiation is produced for research in the form of controllable neutron fluxes, which are very intense fields into which hardware components or electronic, structural, or fuel materials are placed. Objects are tested to determine the effect of radiation on physical properties such as strength, brittleness, or elasticity. Items are exposed to neutron radiation for a specified length of time, removed, and transferred to hot laboratories, which are shielded cells where engineers and technicians can safely analyze the irradiated experiments. Hot laboratories are important because materials exposed to nuclear radiation become radioactive and emit gamma rays. Operators peer through thick glass windows and use claw-like robotic manipulator arms to carry out chemical and physical tests without being exposed to the deadly radiation.

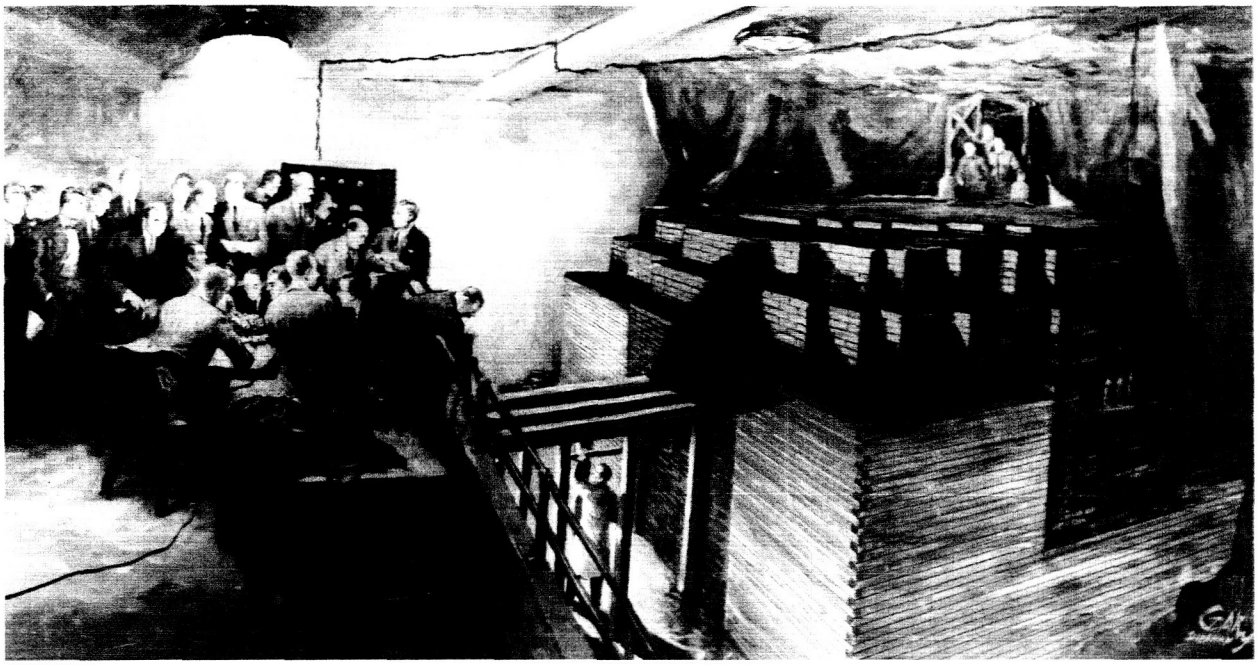


Image 35: Artist's rendering depicting the group of scientists, which included Enrico Fermi, gathered around the first chain reaction on 2 December 1942. The team began work at 8:30 a.m. Slowly, over the course of the morning, they pulled out several of the control rods and monitored the graphs. When an automatic rod accidentally shut down the reaction, Fermi abruptly broke for lunch. The slow, tense operation resumed with rods being withdrawn inches at a time at Fermi's command. At 3:25 p.m., they had achieved the first self-sustaining chain reaction. Twenty-eight minutes later, Fermi ordered Walter Zinn to insert the "zip" rod and the reaction was shut down. (National Archives and Records Administration NWDNS-326-DV-4 [4])

Since the completion of the first nuclear research reactor in 1942 at the University of Chicago, 672 facilities have been built throughout the world. The United States has built the most research and test reactors worldwide, with 227 sites, followed by the former Soviet Union with 97. National laboratories, universities, private industry, and the military constructed these reactors and were responsible for the golden age of research and test reactors in the 1950s and 1960s. During these decades, 193 research facilities became operational, compared to a combined total of only 34 reactors in the years before 1950 and after 1969. These reactors were the centerpiece of the American nuclear initiative after World War II, and invaluable research tools for American scientists who were using radiation for diverse fields of experimentation.

Plum Brook's main nuclear facility was a light-water-cooled and moderated sixty-megawatt test reactor. Additionally there was a 100-kilowatt research Mock-Up Reactor (MUR), which was used to design experiments for the main reactor. In this kind of reactor, the fuel elements were in a pool and the water functioned as a reflector, moderator, and coolant. The AEC recognized that there were such significant differences between research and test reactors that they began to issue separate licenses for them. The Plum Brook Test Reactor was given the number TR-3, which signified that it was the third test reactor licensed in the United States.

The emphasis on testing was what made Plum Brook different from other reactors at the time.[26] The reactor itself had two horizontal holes,

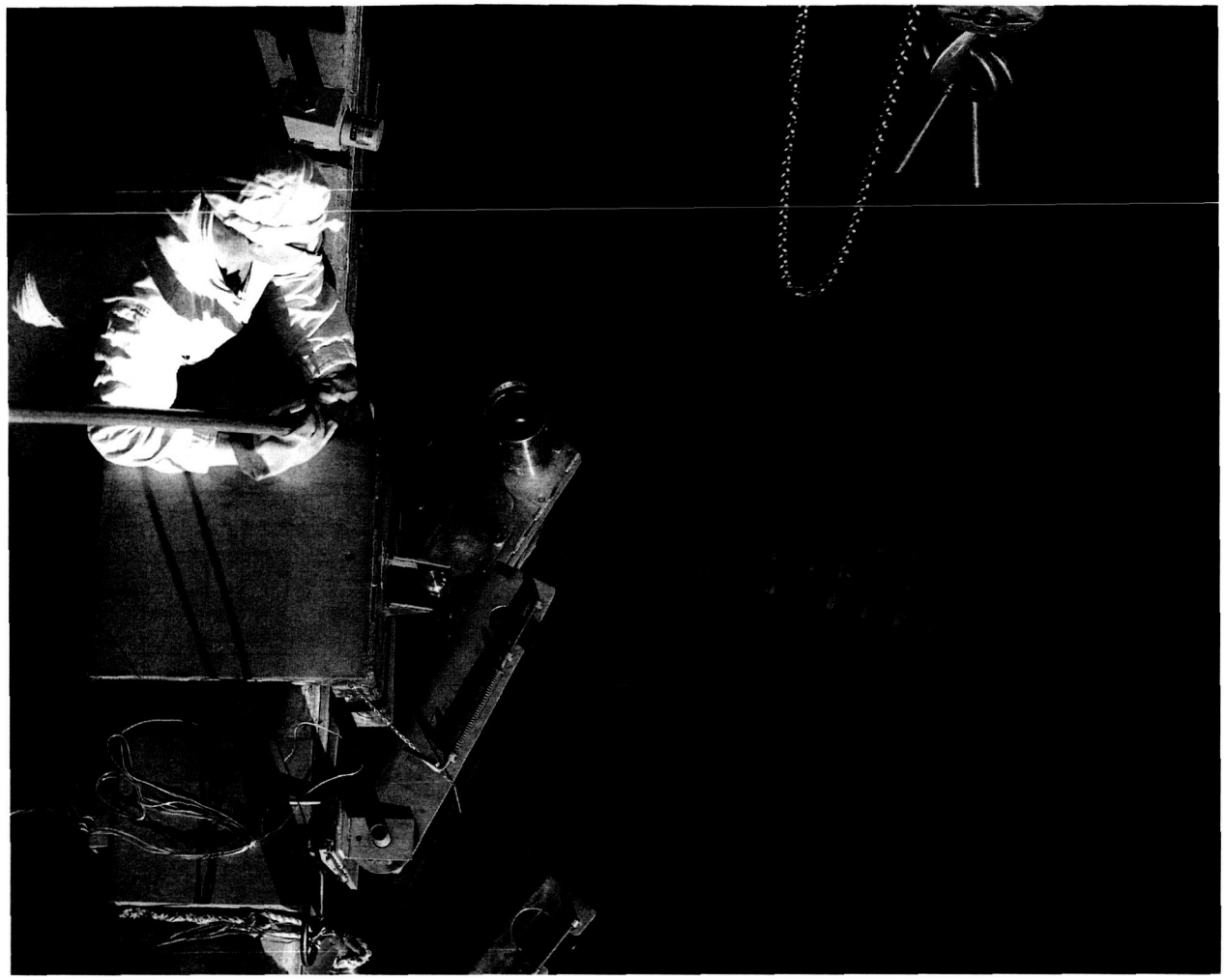


Image 36: View into the reactor core of the Materials Test Reactor (MTR) at Idaho Falls. The 30,000-kilowatt test reactor first went critical on 31 March 1952 and operated until 23 April 1970. The core designs and fuel elements of virtually every American nuclear reactor, including Plum Brook Reactor, were influenced by studies at the MTR. (Department of Energy Photo 1002147)

six horizontal beam holes, and forty-four in-core test locations. Experimental materials could be sent hydraulically into the holes in tiny capsule devices called "rabbits," or they could be irradiated from the neutrons emanating from the beam holes. The engineers would determine the effects on the materials subjected to radiation and this basic research could then be used to help design various components for the nuclear airplane program. The entire facility cost $15 million to build.[27]

In 1956, the NACA sought AEC approval for the construction of the test reactor. The NACA planned that the facility's main area of research would be testing materials for a nuclear airplane. This included the effects of radiation on aircraft components, shield refinement, and related nuclear and solid-state physics. The pump loop experiments were to be the most important. This research would all take place under simulated aircraft reactor conditions. The AEC granted its approval, and in September 1956 the groundbreaking ceremony took place in Sandusky.[28] Congressman A.D. Baumhart, Abe Silverstein, and several NACA leaders spoke at the ceremony, praising the local leadership and stating that Plum Brook was selected in part because of its progressive, forward-thinking community.[29]

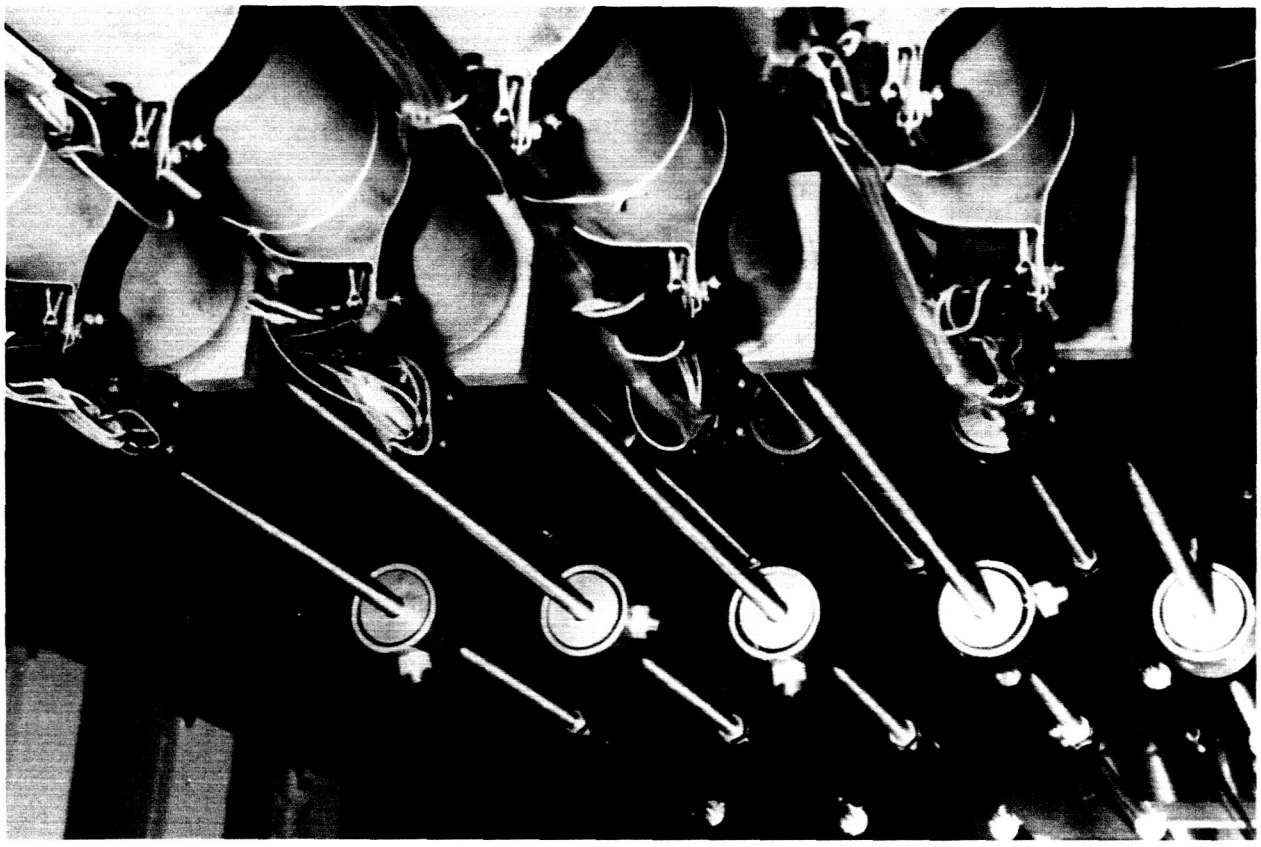


Image 37: Control rods for Plum Brook's Mock-Up Reactor, which entered the core from above. In the Plum Brook reactor, the control rods entered the core from below. Three types of control rods were used in the Plum Brook reactor: two hydraulically controlled regulating rods to provide precise control of the reactor power level; three mechanically controlled reflector rods to provide a coarser level of control (the reflector rods had a quick release to allow them to drop and scram the reactor, if necessary); and five fueled shim rods, which performed the same functions as the reflector rods. (NASA PS63-0007)

Image 38: Atomic Energy Commission (AEC) officials with Abe Silverstein (front row, sitting third from left), working out the final reactor licensing issues. It is said that Silverstein told AEC Director Glenn Seaborg that the officials could not leave until a deal was struck. Because Plum Brook was a federal facility, it was not required to file for an AEC license, but to promote peace of mind in the nearby community and maintain safety, NASA officials decided to work through the commission. They received the AEC designation Test Reactor 3 (TR-3). (NASA C-1964-69271)

Primary Document #3

The following document is an excerpt from a local newspaper article reporting on the groundbreaking ceremonies at the Plum Brook reactor in September 1956.

"BREAK GROUND FOR REACTOR HERE"
The Sandusky Register Star-News
September 26, 1956

Silver pick, shovel start work on Lab.

Nuclear Project at Plum Brook ready in 3 years.

Dr. Edward Sharp, director of the NACA Lewis Laboratory at Cleveland, using a silver shovel, and Congressman A.D. Baumhart, Jr., Vermillion, with a silver pick, loosened the ground to mark the formal start of construction of the reactor which is scheduled to be completed within three years and be staffed by approximately 50 aeronautical scientists and 100 other employees.

Dr. Sharp explained that NACA's primary interest in atomic power is conversion of the energy generated in a reactor to useful thrust in the most efficient manner possible... He added that the airplane powered by the atom will be capable of flying non-stop to any point on earth without refueling, and its flight endurance will be limited only by the endurance of its crew.

Abe Silverstein, associate director of the Lewis Laboratory, said of the reactor: "Despite recent important advances in aerodynamic efficiencies for aircraft at supersonic speeds, nuclear power still is the 'shining hope' for increasing the range of aircraft at high speeds and for increasing aircraft ranges to values obtainable with conventional special chemical fuels. A long range bomber may carry 100,000 pounds or more of fuel. A piece of Uranium 235 with the same energy content would weigh less than one ounce."

LEWIS FLIGHT PROPULSION LABORATORY NACA

WING TIPS

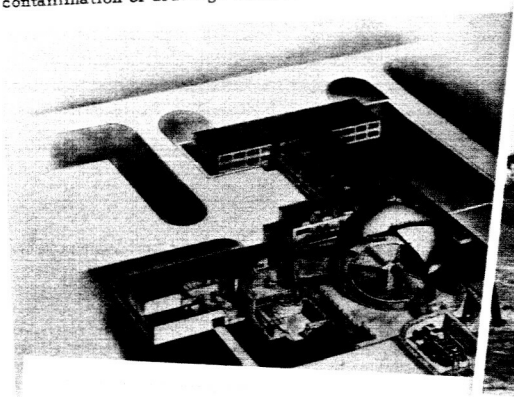
Vol. XV Cleveland, Ohio, September 26, 1956 No. 20

PLUM BROOK RESEARCH REACTOR FACILITY CONSTRUCTION BEGUN

Another forward step in aeronautical progress was made on Wednesday, September 26, 1956 as ground was broken for construction of the NACA's Plum Brook Research Reactor Facility near Sandusky, Ohio. This will be a key link in America's search for the practical solution to the harnessing of nuclear energy to drive the commercial and military aircraft of tomorrow.

Dr. Edward R. Sharp headed a list of government and local officials and civilian guests at the ceremonies. Among the speakers were Dr. John F. Victory, Executive Secretary, and Addison M. Rothrock, Assistant Director for Research.

The NACA is consulting closely with the Atomic Energy Commission in the design of the facility, which will contain elaborate safeguards against any possible hazards to employees or to residents of the area. Safety features include precautions against nuclear contamination of drainage water, and air currents over the facility.



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Constructing the Reactor

The construction of Plum Brook required a great deal of effort between the first groundbreaking in 1956 and first criticality in 1961. During this span of five years, construction efforts reshaped the land and resulted in a powerful nuclear test reactor. The following photographic section documents this effort.

Image 39: Congressman Baumhart watched as Lewis Laboratory Director Dr. Edward Sharp dug the first shovel of dirt at the September 1956 groundbreaking ceremony for the Plum Brook Reactor Facility. The silver pick and shovel are the same ones used for the 1941 groundbreaking of the NACA Lewis Laboratory in Cleveland, Ohio. (NASA C–1956–43032)

Image 40: Controlled fire to demolish unwanted Ordnance Works structure. Upon taking possession of Plum Brook, the NACA inventoried all the Ordnance Works structures and decided to retain forty-one of them, demolishing over 600 other buildings. In addition, three TNT areas and underground waste disposal lines had to be destroyed and decontaminated. (NASA C–2003–829)

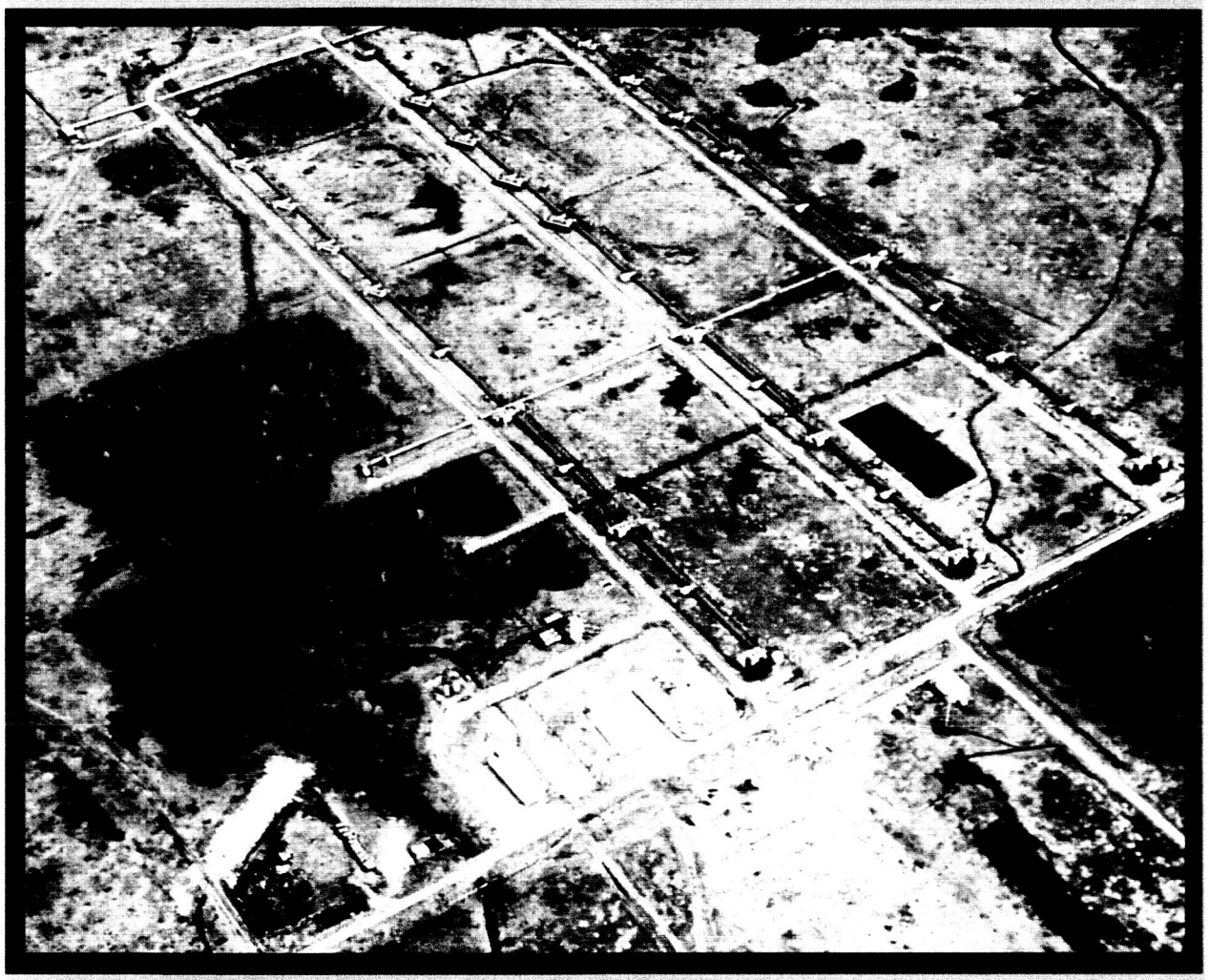


Image 41: The Plum Brook Ordnance Works' Pentolite Area was demolished and decontaminated. It was on these 117 acres of land that the reactor facility was constructed. (NASA CS–18957)

Image 42: The Plum Brook Reactor Facility construction began when crews excavated a hole in the ground for the pressure tank. The tank extended approximately thirty-two feet under ground. The steel containment vessel, which was more than 100 feet high (fifty-five feet above grade and fifty-six feet below grade), surrounded the reactor tank area and the surrounding quadrants and canals. It was designed to prevent any radioactivity from being released if an accident were to occur in the reactor. This safety precaution was essential because of the nearby communities. Many other large reactors did not have such safety features. For example, the Materials Test Reactor in Idaho Falls had no shield because small amounts of contamination could be released into the atmosphere without endangering the public. (1958–60) (NASA C–2003–830)

Image 43: Exterior of the containment vessel during construction. (NASA C-2003-831)

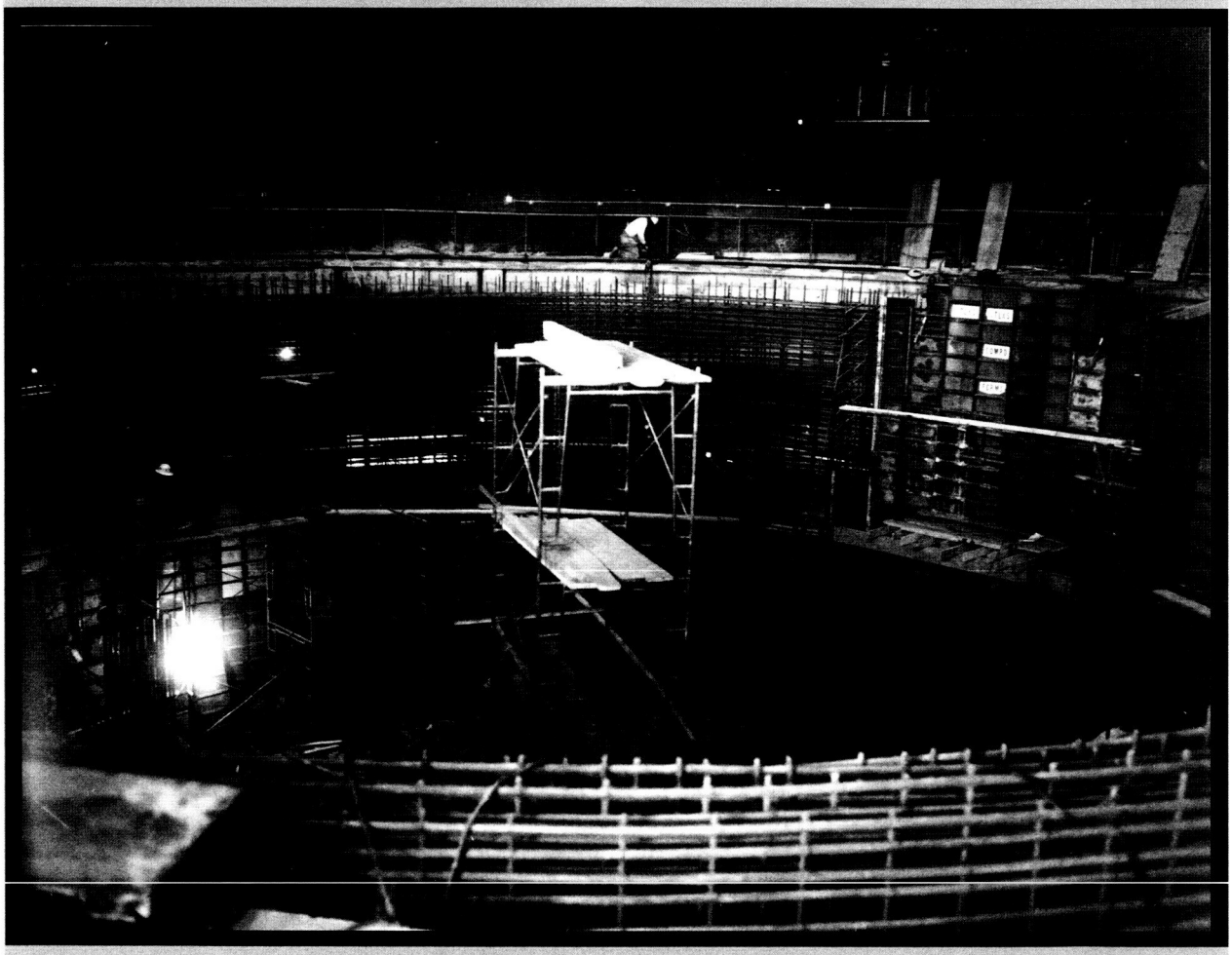


Image 44: Inside the containment vessel during construction. (NASA C–2003–832)

Image 45: The pressure tank was shipped to Plum Brook via railway, and transported to the reactor facility on a flatbed truck. The tank was then rolled to a crane, which lifted it into place at the center of the unfinished quadrant area. Several pipes jutted out from the tank. These "test holes" would be used to transport experiments to the reactor core for radiation during its operating cycles. (c. 1959) (NASA C–2003–833)

Image 46: The pressure tank delivered by truck. (NASA C–2003–834)

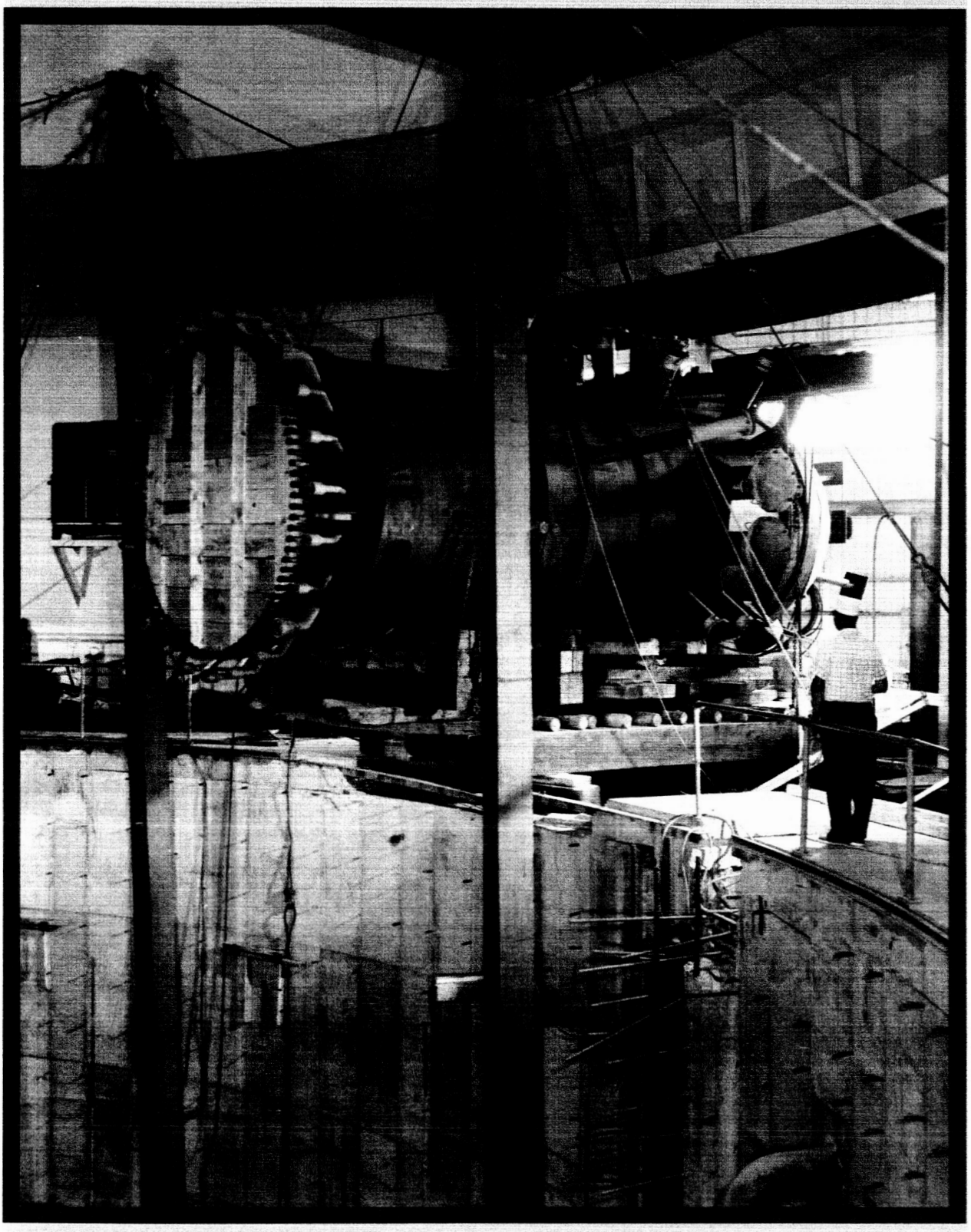


Image 47: Pressure tank being lowered into the containment vessel. (NASA C–2003–835)

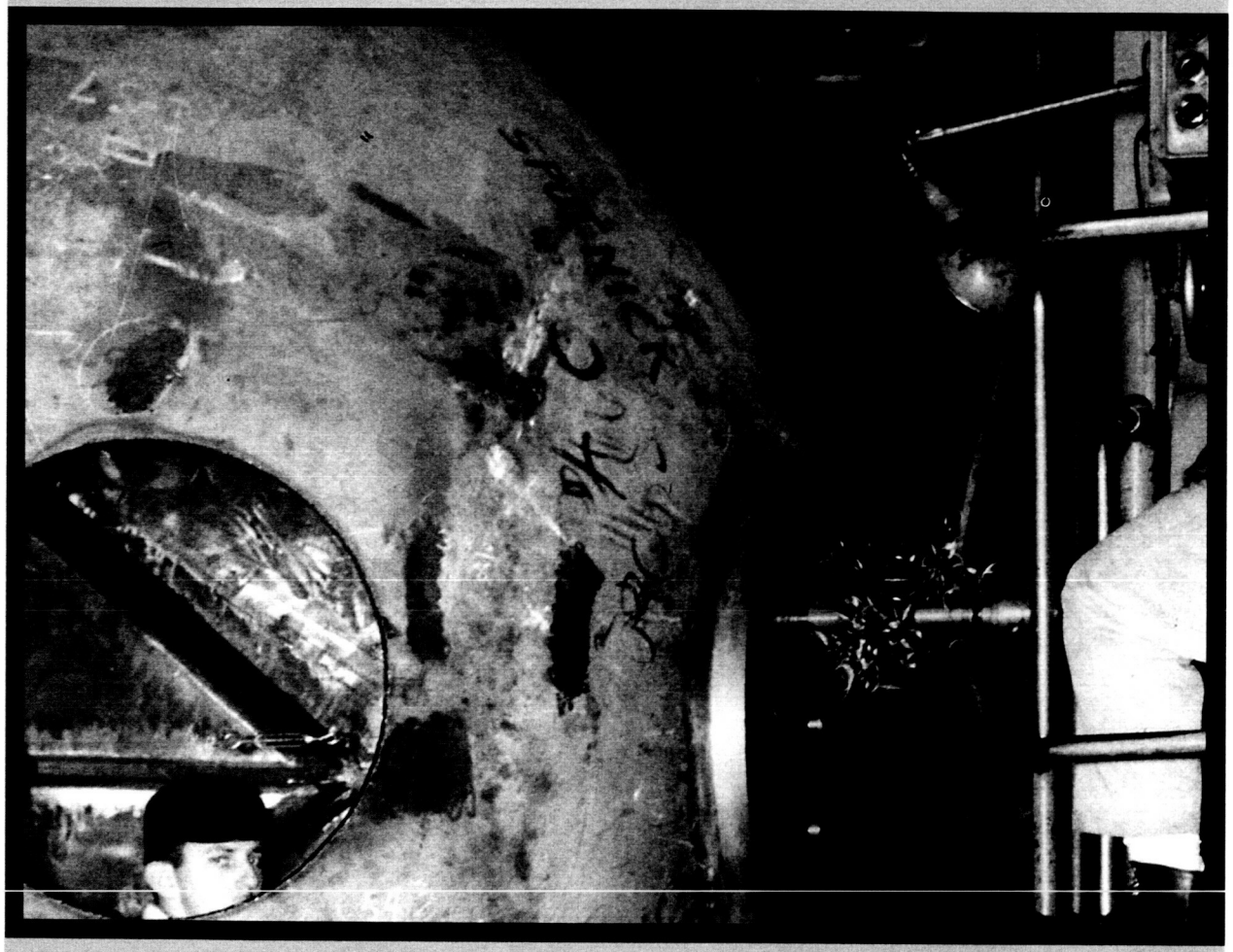


Image 48: Because it bore a resemblance to the Soviet's first orbiting satellite, engineers scrawled the word "Sputnick" into the side of the pressure tank. Though misspelled, this was perhaps a not-so-subtle reminder of the Cold War space race. It was hoped that the basic experimental science conducted at Plum Brook would play a vital role in the development of a nuclear rocket. (NASA C-2003-835)

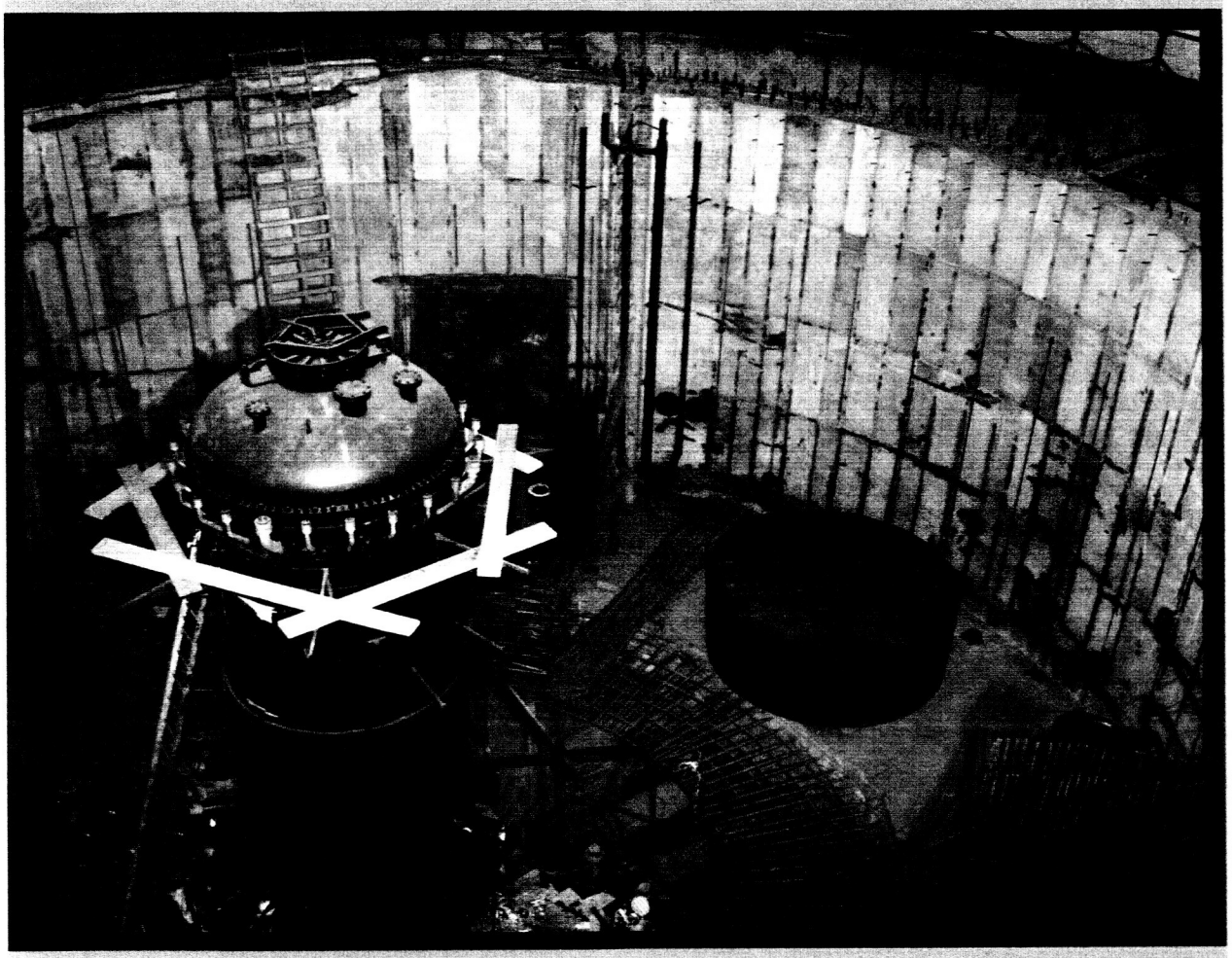


Image 49: The pressure tank in place inside the containment vessel. (NASA C–2003–836)

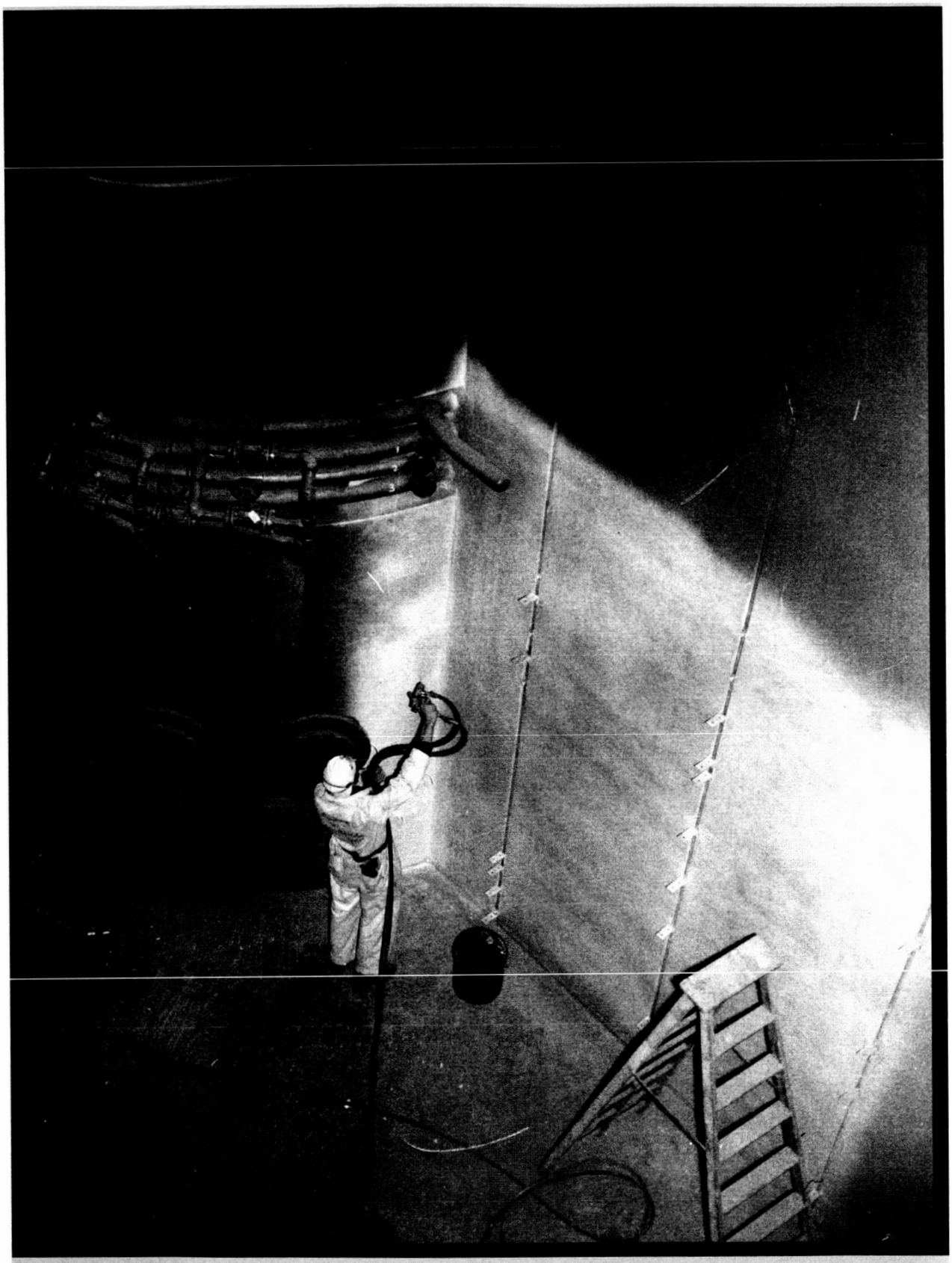


Image 50: A worker spray paints one of the quadrant walls and a shielding wall surrounding the reactor pressure tank. The quadrants were twenty-five to twenty-seven feet deep and filled with water. The water provided shielding for the radioactive materials that were transported along the canal basin. (NASA C–2003–837)

Image 51: Plum Brook had two pumping stations to obtain raw water from nearby Lake Erie. The reactor required one million gallons of water daily for cooling, shielding, and dilution of radiation. The main one was at Rye Beach (pictured) and the other was at Big Island. They were initially constructed in 1941 for the Ordnance Works and were closed in late 1945. In March 1958, NACA assumed control of both facilities, but it took several years of repairs and cleaning before both would consistently function properly. They were connected to Plum Brook by 5.9 miles of 24-inch steel piping. Together, they could pump 51 million gallons of lake water per day. (1983) (NASA C–2003–838)

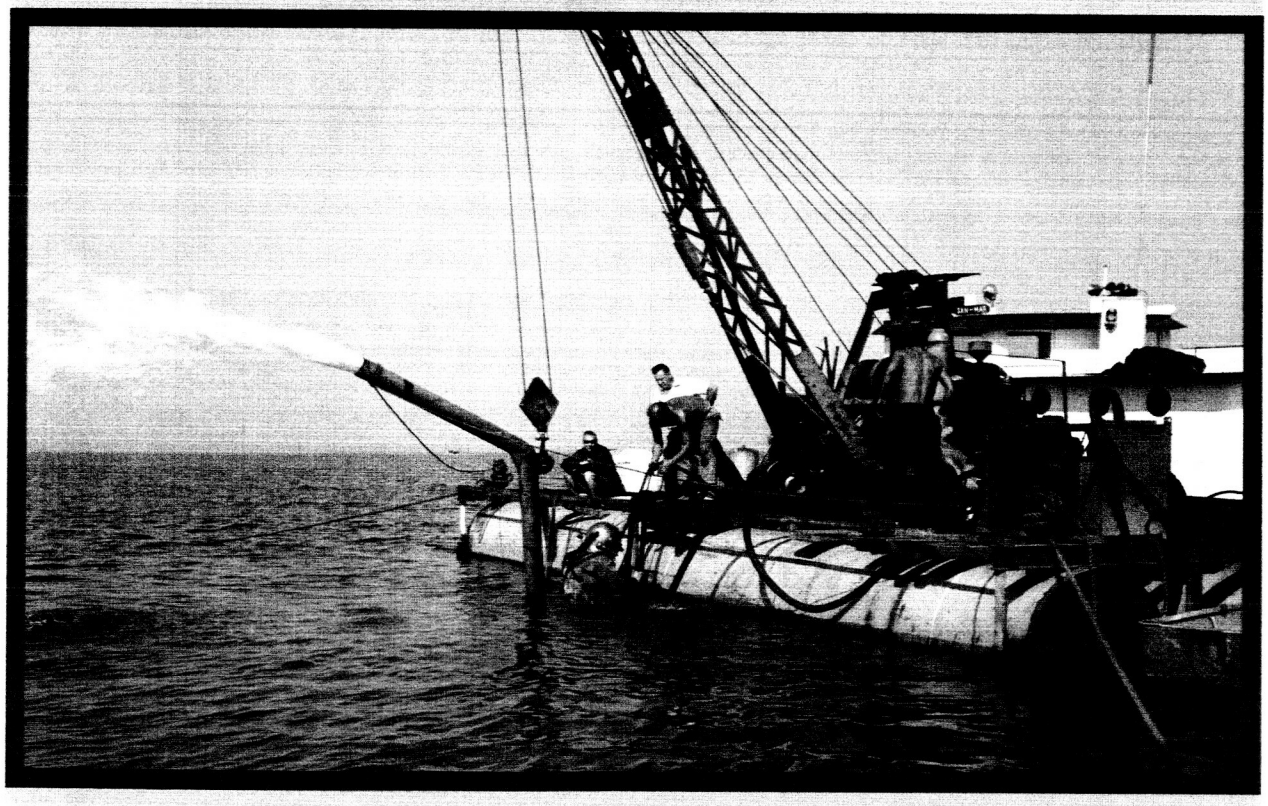


Image 52: A diver emerges after working on the Plum Brook water pumps in Lake Erie. Divers had to flush the intake line and clear it of mud, silt, and debris regularly. (NASA C–1961–58167)

Image 53: The Plum Brook Guardhouse. (NASA C–2003–850)

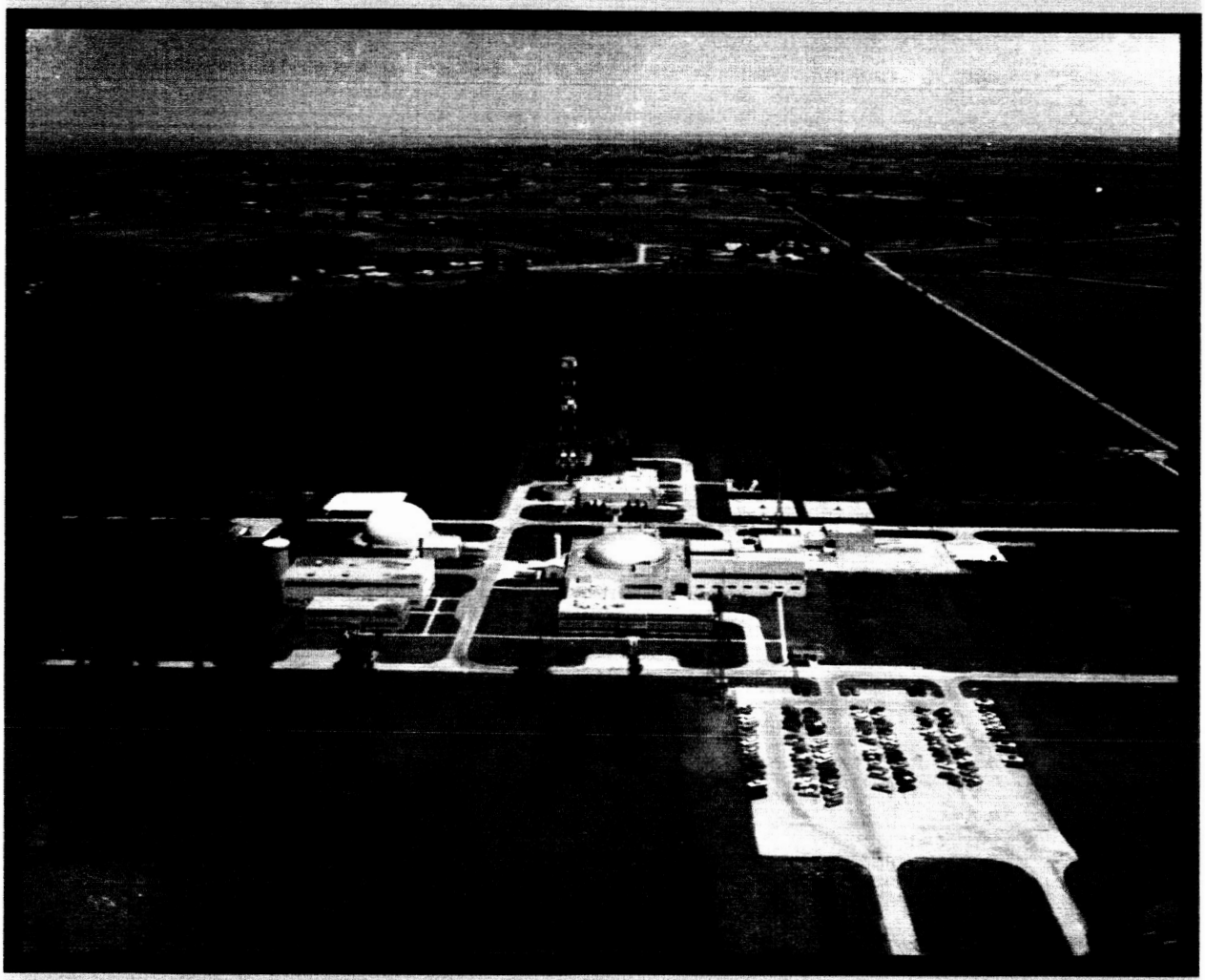
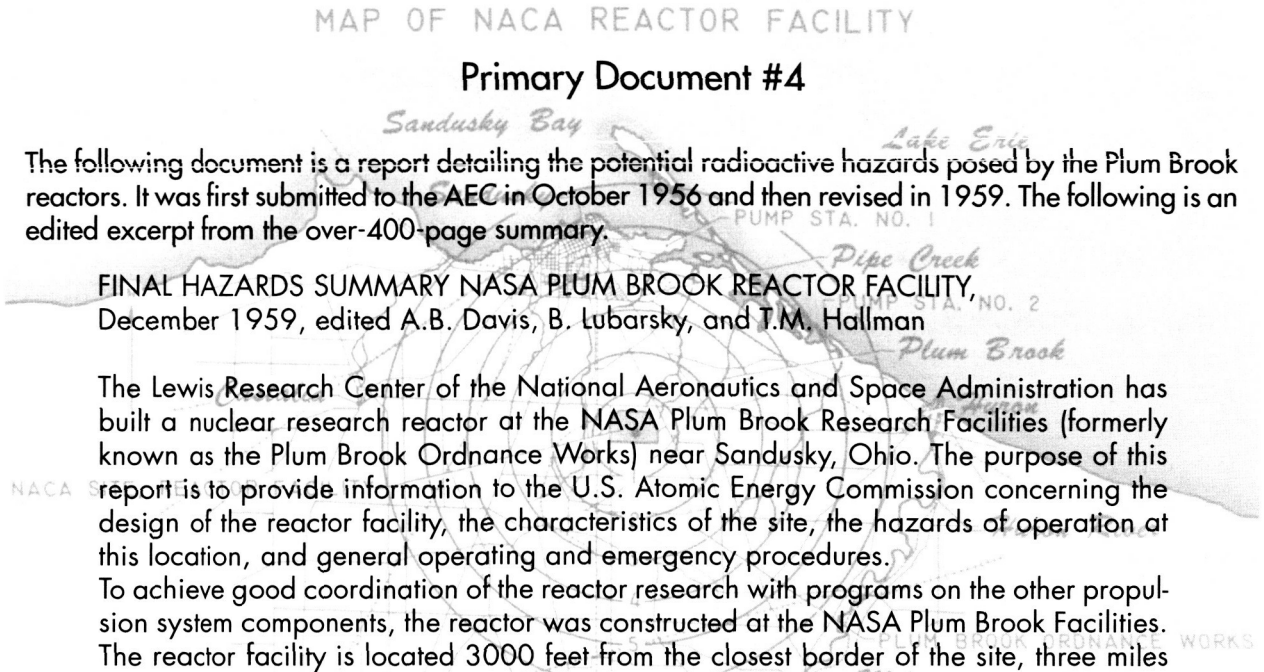


Image 54: The Plum Brook reactor complex consisted of numerous research facilities and support buildings. The containment vessel's silver dome was at the center of the main reactor building. The reactor office and lab building was located in the immediate foreground, and the hot laboratory was adjacent on the right. Across the road to the left was the reactor office building, and assembly, test, and storage building. Behind it was the large, white helium storage structure. Behind the reactor building were the service equipment building, the cooling tower, and the water tower. The fan house and waste-handling building were behind the hot laboratory. (1969) (NASA C–1969–10920)



Primary Document #4

The following document is a report detailing the potential radioactive hazards posed by the Plum Brook reactors. It was first submitted to the AEC in October 1956 and then revised in 1959. The following is an edited excerpt from the over-400-page summary.

FINAL HAZARDS SUMMARY NASA PLUM BROOK REACTOR FACILITY, December 1959, edited A.B. Davis, B. Lubarsky, and T.M. Hallman

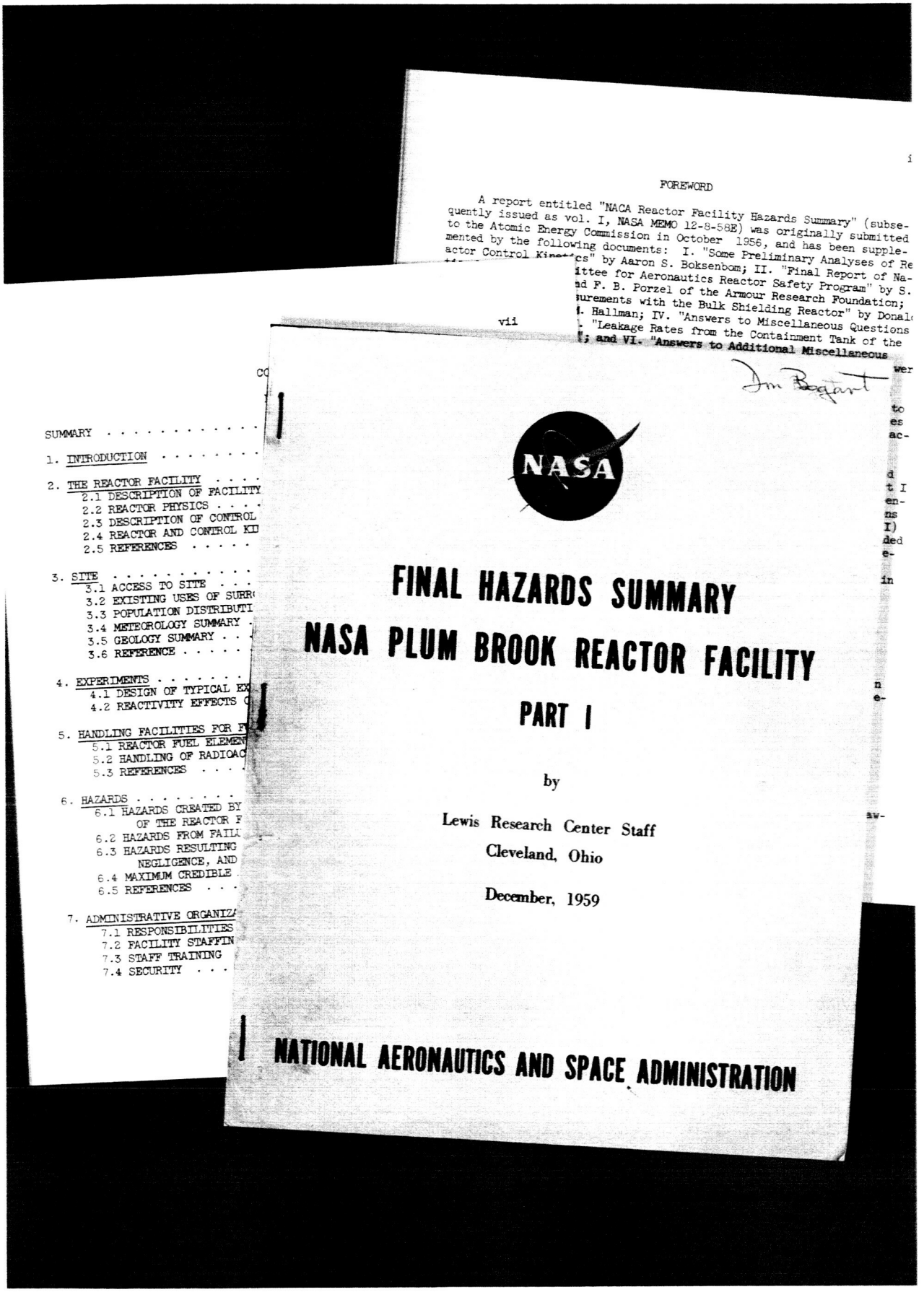
The Lewis Research Center of the National Aeronautics and Space Administration has built a nuclear research reactor at the NASA Plum Brook Research Facilities (formerly known as the Plum Brook Ordnance Works) near Sandusky, Ohio. The purpose of this report is to provide information to the U.S. Atomic Energy Commission concerning the design of the reactor facility, the characteristics of the site, the hazards of operation at this location, and general operating and emergency procedures.
To achieve good coordination of the reactor research with programs on the other propulsion system components, the reactor was constructed at the NASA Plum Brook Facilities. The reactor facility is located 3000 feet from the closest border of the site, three miles from Sandusky, a city of 35,000 people, and fifty miles from the Lewis Research Center in Cleveland, Ohio.

During the period when the site for the NASA reactor was selected, consideration was given to a more remote site such as the NRTS [National Reactor Testing Station] site in Idaho. The NASA Plum Brook Facilities offered a number of advantages compared to a site of this type.

The surrounding population density is the chief disadvantage of the Plum Brook Site compared to a more remote location. This factor may prohibit the performance of a few very hazardous experiments at this site. Any experiment vital to the progress of scientific knowledge or nuclear propulsion which is deemed too hazardous for the Plum Brook Site, could readily be carried out at MTR [Materials Test Reactor] or ETR [Engineering Test Reactor]. This fact minimizes this disadvantage of the Plum Brook Site.

An analysis of the consequences of failure or malfunction of equipment has been made for the purpose of estimating the consequences of the unplanned release and dispersion of radioactive materials. The analysis deals with accidents which may introduce hazards from the following sources: (1) Failure or malfunction of component parts of the reactor or of component parts of the reactor cooling, electrical, or control system. (2) Failure or malfunction of experiments in any of the radiation facilities of the research reactor. (3) Acts of God, sabotage, negligence. (4) Maximum credible accident.

[A maximum credible accident] is the excursion resulting from the inability of the control system to compensate for the addition of a large step-increase in reactivity to the reactor. In this excursion, the reactor power and temperatures increase rapidly until some inherent self-limiting process in the reactor stabilizes the situation or until the reactor disassembles itself. The runaway to destruction in a reactor of this type would probably include the melting of the fuel plates, an explosion in the reactor pressure tank, and the scattering of radioactive materials. It is an event which could create a considerable hazard both for the operating personnel and the general populace.



FOREWORD

A report entitled "NACA Reactor Facility Hazards Summary" (subsequently issued as vol. I, NASA MEMO 12-8-58E) was originally submitted to the Atomic Energy Commission in October 1956, and has been supplemented by the following documents: I. "Some Preliminary Analyses of Reactor Control Kinetics" by Aaron S. Boksenbom; II. "Final Report of National Committee for Aeronautics Reactor Safety Program" by S. Lawrence and F. B. Porzel of the Armour Research Foundation; III. "Measurements with the Bulk Shielding Reactor" by Donald J. Hallman; IV. "Answers to Miscellaneous Questions" by [illegible]. "Leakage Rates from the Containment Tank of the [illegible]; and VI. "Answers to Additional Miscellaneous

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FINAL HAZARDS SUMMARY
NASA PLUM BROOK REACTOR FACILITY
PART I

by

Lewis Research Center Staff
Cleveland, Ohio

December, 1959

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Kennedy's New Dream

During the five years of Plum Brook's construction, both the government and the U.S. Air Force lost their enthusiasm for the nuclear airplane program. It turned out that the reports stating that the Soviet Union was close to building its own nuclear airplane were untrue. Also, progress on traditionally fueled airplanes enabled them to begin performing at levels that were once thought achievable only by a nuclear airplane. Bombers were now able to fly to Moscow and back, and intercontinental ballistic missiles (ICBMs) armed with small nuclear warheads could be launched from the United States and accurately hit targets in the Soviet Union. In March 1961, President John F. Kennedy delivered a message to Congress on the defense budget, which became known informally as the "kiss of death for the atomic plane." He said that despite the time and money (fifteen years and $1 billion) that had been sunk into the project, "the possibility of achieving a militarily useful aircraft in the foreseeable future is still very remote." As a result he planned to "terminate development effort" on the nuclear airplane.[30]

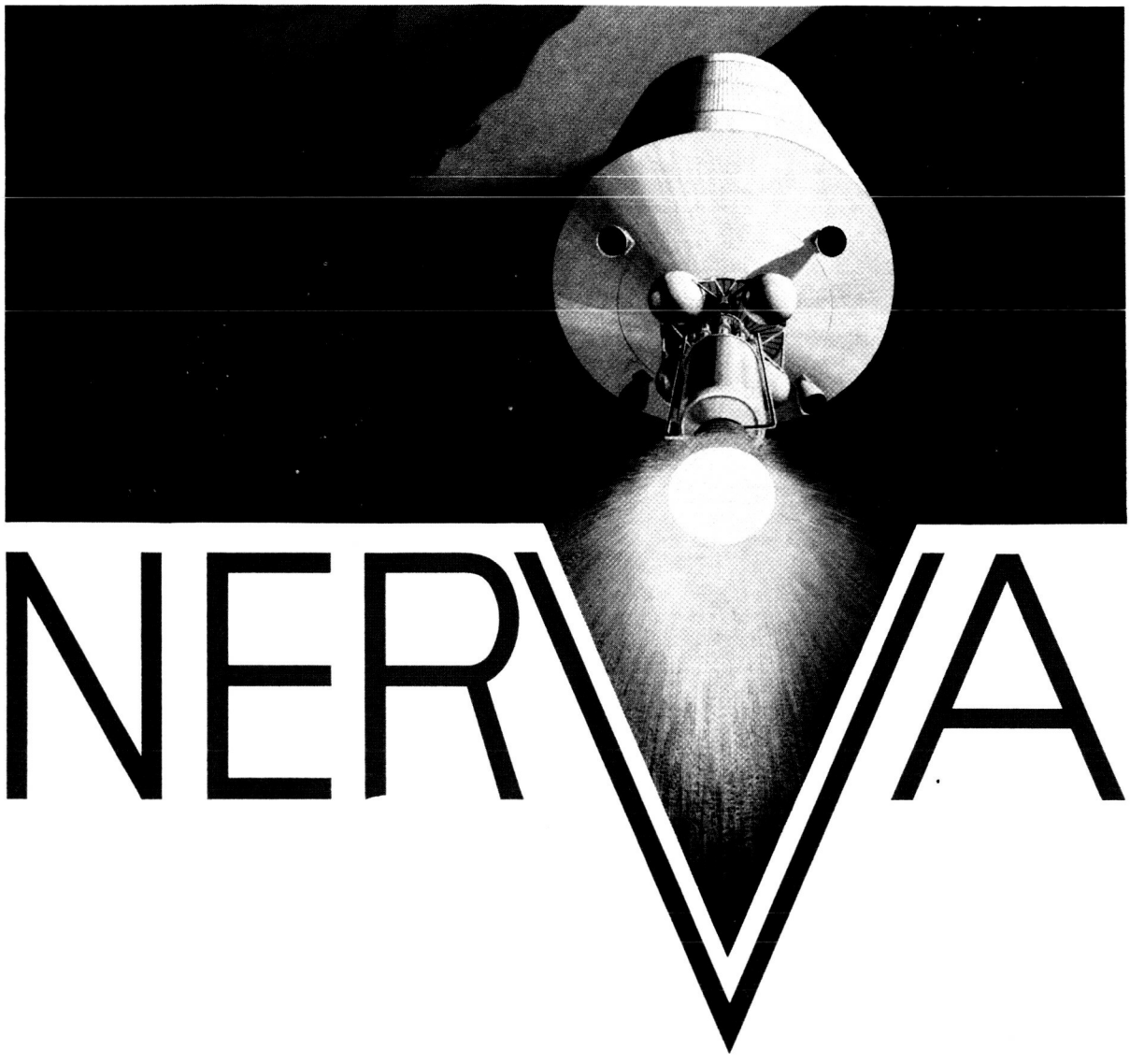
Suddenly, just months before the Plum Brook reactor was to go critical (meaning that it would be able to sustain a nuclear reaction or reach criticality), its primary research objective was eliminated. But the Plum Brook engineers, still finishing construction on their facility, did not have to wait long to have a new assignment handed to them. Despite the end of the nuclear airplane, Kennedy did not lose his enthusiasm for nuclear technology. The nation had also been working on a nuclear space initiative since 1955, and this was the brave new world that Kennedy wanted to explore. Less than two months later he delivered his famous "Urgent National Needs" speech before a joint session of Congress about landing a man on the Moon before the decade was out. He said, "Now it is time to take longer strides—time for a great new American enterprise—time for this

Image 55: President Kennedy emerges from a tour of the nuclear rocket test facilities at Jackass Flats, Nevada. At his right is the head of the Atomic Energy Commission, Glenn Seaborg, and in front of him is Harold Finger, the head of the joint AEC-NASA Space Nuclear Propulsion Office. (Harry Finger Collection)

nation to take a clearly leading role in space achievement, which in many ways may hold the key to our future on Earth." He wanted the entire nation to commit itself to achieving this goal quickly and efficiently as before its rival superpower, the Soviet Union, could do so. What is often forgotten about this speech is that Kennedy also advanced an even more compelling dream. Though just months before he had cancelled the nuclear airplane, now he called for increased funding to develop a nuclear rocket. He said, "This gives promise of some day providing a means for even more exciting and ambitious exploration of space, perhaps beyond the Moon, perhaps to the very end of the solar system itself."[31]

The development of a nuclear rocket was a highly complex undertaking (even more so than the nuclear airplane), and advanced research facilities like Plum Brook would play a role in its development. One important advantage of the nuclear rocket was its high specific impulse (a measure of the miles per gallon that would be possible with hydrogen fuel propellant, which

Image 56: President Kennedy operates a remote manipulator like the ones found in the hot laboratory at Plum Brook. This one was used to disassemble radioactive parts from a nuclear rocket reactor that had been sent to Los Alamos from the Nuclear Rocket Development Station at the Nevada Test Site. Harold Finger accompanied him on the trip and recalled, "There's no question about it. [Kennedy] enjoyed seeing the equipment. He actually played with some of the remote manipulators and I can tell you he was beaming as he was doing it. After meeting these outstanding scientists at Los Alamos and seeing the facilities in Nevada, he was really excited about the whole thing."[32] (Harry Finger Collection)



NERVA

SPRINGBOARD TO MARS AND VENUS

NERVA—**N**uclear **E**ngine for **R**ocket **V**ehicle **A**pplication. Now being developed as the nation's first nuclear powered rocket engine, NERVA will permit extensive space explorations, including delivery of extremely large payloads to the nearest planets. As part of the Rover nuclear rocket propulsion program, NERVA will be flight tested on an advanced SATURN booster in combination with a nuclear powered upper stage. ■ Development of the NERVA engine is the responsibility of REON (Rocket Engine Operations—Nuclear), an organization which manages and directs the development of nuclear rocket systems for the Aerojet-General® Corporation. Westinghouse Astro-Nuclear Laboratories shares the responsibility for the NERVA reactor under the team leadership of REON. The over-all Rover program is under the direction of the Space Nuclear Propulsion Office, a joint office of the Atomic Energy Commission and the National Aeronautics and Space Administration.

AEROJET GENERAL TIRE GENERAL T.M.

REON
AZUSA, CALIFORNIA

Image 57: An advertisement for NERVA, the Nuclear Engines for Rocket Vehicle Applications program. Aerojet General Corp. and Westinghouse were primary contractors who operated under NASA–AEC's Space Nuclear Propulsion Office. (Harry Finger Collection)

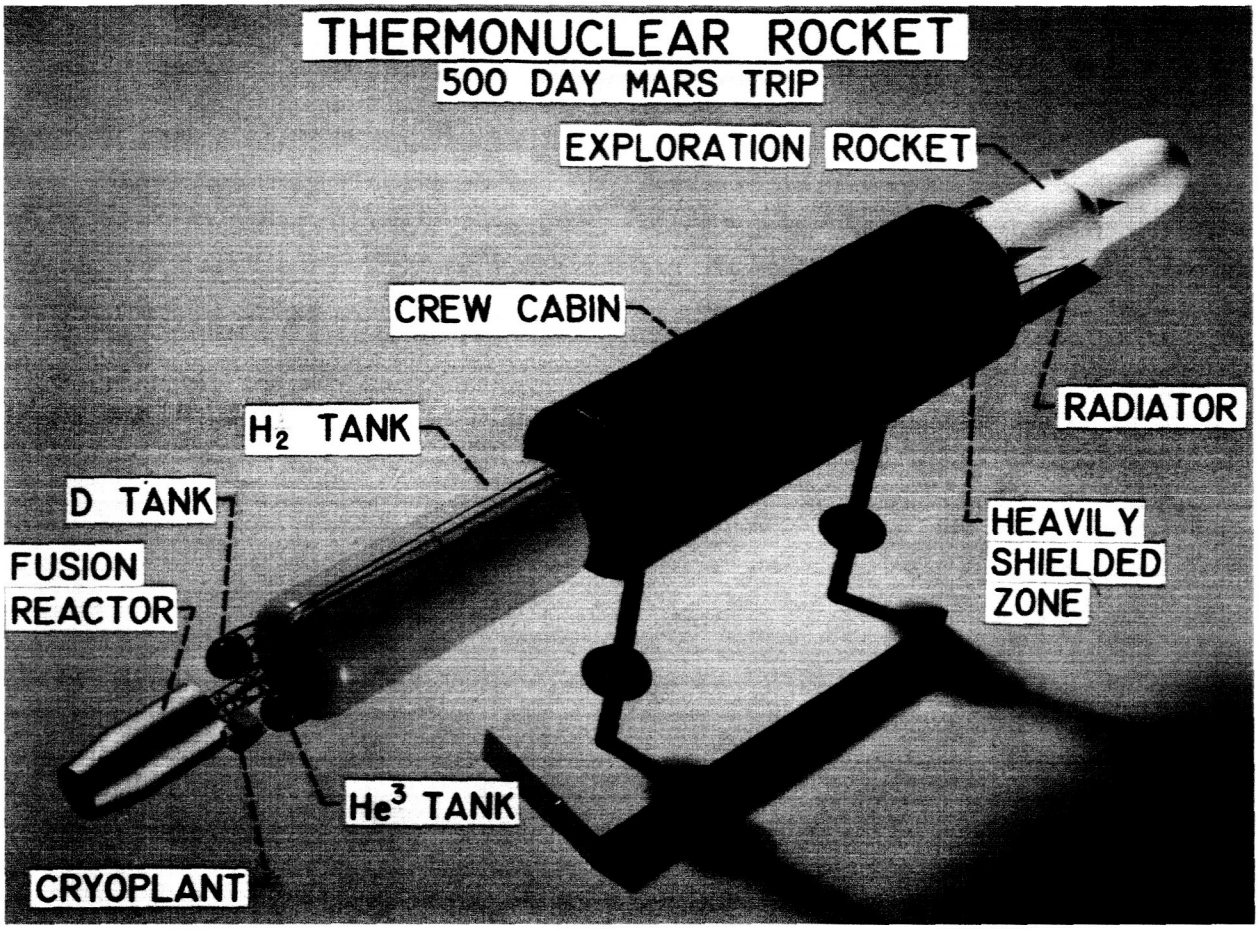


Image 58: A model of a thermonuclear rocket capable of interplanetary exploration. The reactor was used to heat up liquid hydrogen for thrust similarly to traditional rocket engines. The large heavily shielded zone between the reactor and the crew cabin protected the astronauts from the radiation. (1963) (NASA C-1963-63470)

would be used in tandem with a nuclear rocket), due to the high operating temperature of the reactor. Though scientists had harnessed the power of the atom for nuclear bombs twenty years earlier, there was still much to learn about the effects of radioactivity. Building a nuclear rocket presented many scientific, technical, and human questions. For example, how quickly would materials exposed to radiation (both from space and the reactor itself) become weak and deteriorate? What types of materials endured best in these environments? Which of these materials provided the greatest radiation-shielding capabilities to ensure the safety of the astronauts traveling with it? Important questions also surrounded temperature. For example, what would be the effects of radiation and high temperatures on the reactor and the rocket's engines? Did cryogenic temperatures also have an effect upon performance? The search for these answers became the responsibility of scientists and engineers working at nuclear research and test reactors around the country.[33] Just twenty days after Kennedy gave his speech, the Plum Brook reactor went critical and became the second most powerful American test reactor facility.

Primary Document #5 and #6

Just seven days before President Kennedy officially canceled the atomic airplane, Plum Brook held a massive open house to demonstrate the reactor that was constructed to support development of this project. More than sixty members of the print media and radio and television news services met at the site to talk with community leaders and NASA and AEC representatives. To see the dramatic change of focus for the reactor, compare the following two excerpted newspaper reports. The first article, "Reactor for A-Plane Gets Okay," appeared in early March when the Plum Brook reactor was set to support the atomic airplane. The second article, "Plum Brook Atomic Lab Brings Space Closer," appeared less than two weeks later and made no mention of the atomic airplane,although it discussed space and nuclear rocket research.

"REACTOR FOR A-PLANE GETS OKAY"
Chillicothe Gazette
8 March 1961

The Plum Brook research nuclear reactor, to be used in efforts to develop an atomic airplane, has received the Atomic Energy Commissions approval to go into operation. The reactor, the nation's second largest with power equivalent to 60 million watts, is a facility of Cleveland's Lewis Research Center, which operates under the National Aeronautics and Space Administration... Scientists hope to develop a fuel, a couple of pounds of which would enable an airplane to fly many times around the world.

NASA has said the entire installation was designed to withstand any foreseeable accident without releasing any hazardous materials or gases. The reactor is contained in a steel tank three-quarters of an inch thick. The tank is encased in three feet of concrete for more protection. Surrounding the tank is a pool 70 feet in diameter that will be filled with water for further protection.

"PLUM BROOK ATOMIC LAB BRINGS SPACE CLOSER"
The Cleveland Press
21 March 1961

U.S. effort to harness nuclear power for rockets and space flight takes a giant step today with completion of the Plum Brook Reactor Laboratory three miles south of Sandusky. This is the first laboratory of its kind built by the space agency and the only nuclear reactor in Northern Ohio...

Civic officials of Sandusky and top scientists from Lewis participated in opening ceremonies at the laboratory today. Lewis officials described an extensive program to guarantee that the facility and its environs will be kept free from radioactive contamination.

NUCLEAR REACTOR'S CONTROL ROOM contains a vast assortment of instruments to ensure safe operation and shutdown of the atomic reactor. A licensed operator directs activities here in the nerve center, and from this console t staff expects to start-up the reactor for the first time ne month.

Lewis to Control Sandusky Reactor

The Plum Brook research ground under controlled condi-
reactor, the nation's newest fa- tions the radiation environment
especially for of nuclear power plants.
of the experiments sched-
sensitive electronic components.

The Atomic Energy Commission which operates or licenses 131 reactors in the U
ally completed. Total cost about $15,000,000.

Operated as part of
ANCE
SCENT NEWS

Unveil Sandusky Nuclear Reactor

SANDUSKY, Ohio (UPI)—The National Aeronautics and Space Administration today showed off its Plum Brook reactor laboratory with a promise the latest in safety devices will be used to prevent radioactive contamination of the area.

The $10 million facility will be used for the study of advanced reactor materials, heat transfer and shielding on rockets.

NASA officials said when the laboratory begins operation it will be a major step in using nuclear power for rockets and space flight.

The reactor is the only one in northern Ohio.

Civic officials, newsmen, and officials of NASA from Washington and the NASA Lewis Research Center at Cleveland Hopkins Airport toured the laboratory today.

All persons working here will wear badges of film which will register the individual's exposure to radioactivity.

The smallest amount of radioactivity will be visible instantly because the color of the film in the badge will change when exposed to radioactivity.

Evacuation Plan Set

Plans for immediate evacuation of the facility if ever necessary have been drawn.

The reactor, three miles south of Sandusky, is the first of its kind built by NASA.

The reactor is one of several in the pointing up, officials said, importance of the Buckeye State in the development of uses of nuclear energy. At Piqua, for example, a nuclear plant is being built to generate electricity.

The reactor here is a materials testing reactor, light, water-cooled and moderated, with a primary beryllium reflector and a secondary water reflector. The initial core will be a 3x9 array of fuel elements.

The fueled reactor is mounted in a steel cylinder. There are three cylinders, one inside the other, which serve as heat shields and provide protection against damage.

Reactor for Atom Plane Project Will Be Started

SANDUSKY, Ohio (AP) — The Plum Brook research nuclear reactor, to be used in efforts to develop an atomic airplane, has received the Atomic Energy Commission's approval to go into operation.

The reactor, the nation's second largest with power equivalent to 60 million watts, is a facility of Cleveland's Lewis Research Center, which operates under the National Aeronautics and Space Administration.

The $11 million project, begun in 1956, also will be used for research in atomic-powered missiles and space craft. Scientists hope to develop a fuel, a couple of pounds of which would enable an airplane to fly many times around the world.

NASA has said the entire installation was designed to withstand any foreseeable accident without releasing any hazardous [illegible] or gases.

steel tank three-quarters of inch thick. The tank is encased three feet of concrete for protection. Surrounding the ta is a pool 70 feet in diameter th will be filled with water for fu ther safety.

In the event of a misha whistles, bells, sirens, flashin lights and other gadgets will giv warning.

An AEC spokesman said a rec ommendation by AEC Examine J. D. Bond in Washington Tuesday gives NASA a temporary permit to operate the reactor effective about the middle of April—assuming no objections are raised by the [illegible] or other interested par-

approved by bond

50 Visiting Newsmen To See Reactor Here

More than 50 newspapermen, radio and television representatives will get a final look at the nuclear reactor south of Sandusky on Tuesday morning. The reactor, a facility of the National Aeronautics and Space Administration, is expected to be "fired up" with nuclear fuel in the near future.

Visiting newsmen started arriving in Sandusky this afternoon and checked into hotels and motels for the night. At 6 p.m. today they will be guests of the Sandusky Area Chamber of Commerce at a press reception in Hotel Rieger. William H. Smith is general chairman of the Chamber's press party committee.

In addition to visiting newsmen, the Chamber of Commerce has invited city, county, state and federal representatives to the reception. The C-C board of directors will also be on hand to welcome visiting NASA officials and newsmen to the city.

Coming to Sandusky from NASA's main office in Washington will be James O'Neil, deputy director; Leonard Mandelbaum, office of general counsel of NASA and David Novik, office of advance research, who was formerly a research scientist at the Lewis Research Center, Cleveland.

Milton Kline, an AEC headquarters executive, will also be present, along with Congressman Charles A. Mosher.

Tuesday morning the visitors will be served breakfast at the Sandusky High School caleteria, after which they will go to the school auditorium for a briefing session, followed by a tour of the reactor.

Sandusky Reactor Key To Atomic Plane Try

SANDUSKY, Ohio (AP) — The Plum Brook research nuclear reactor, to be used in efforts to develop an atomic airplane, has received the Atomic Energy Commission's approval to go into operation.

The reactor, the nation's second largest with power equivalent to 60 million watts, is a facility of

lights and other gadgets will give warning.

An AEC spokesman said a recommendation by AEC Examiner J. D. Bond in Washington Tuesday gives NASA a temporary permit to operate the reactor effective about the middle of April—assuming no objections are raised by the commission or other interested

For Atomic Flight Research

NASA Shows Off Its Plum Brook Reactor

SANDUSKY, Ohio (AP) — The National Aeronautics and Space Administration today showed off its Plum Brook reactor, where researchers hope to overcome some of the obstacles on the road to nuclear powered flight.

Future spacecraft will be propelled or powered by nuclear reactors. NASA spokesmen told newsmen gathered to look at the new facility.

"Advanced" materials that might be used in a nuclear reactor will be tested in the Plum Brook reactor, which simulates the nuclear radiation conditions that would be found in such spacecraft.

Thus, scientists can study possible materials for shielding, fuel elements and other reactor components without building complete reactor systems.

The Plum Brook reactor, to be operated by the Lewis Research Center, Cleveland, is to go into operation early next month. The first fuel elements loaded into the reactor will give it a potential thermal power of 60 megawatts.

The heart of the plant is a reactor that stands just a mite over 2 feet high. This is mounted in a steel-clad pressure vessel 8 feet in diameter and 32 feet high.

The pressure vessel, which has a heavy steel cover to shield against gamma rays and against possible shrapnel damage in the event of an explosion, is surrounded by concrete at least 2 feet thick.

All this is at the center of a pool of water 70 feet in diameter and 25 feet deep.

Materials to be tested are inserted in holes in the reactor. One of the holes is directly against the fuel elements and surrounded by beryllium.

The 25-foot water depth provides adequate shielding from radiation and still affords researchers a view of what is going on in experiments.

Materials can be removed by remote control for examination in adjacent laboratories.

The plant is located on property formerly occupied by the Plum Brook Ordnance Works, where the Army made explosives and stored ammunition during World War II. Most of Plum Brook has been allocated to Lewis Research Center. NASA noted that it is an excellent location for a research reactor, remarking in a prepared statement that:

"The well-watered site drains toward Lake Erie and drainage can be controlled by dikes. Winds are predominantly from the southwest and blow over a relatively sparsely populated area toward the lake."

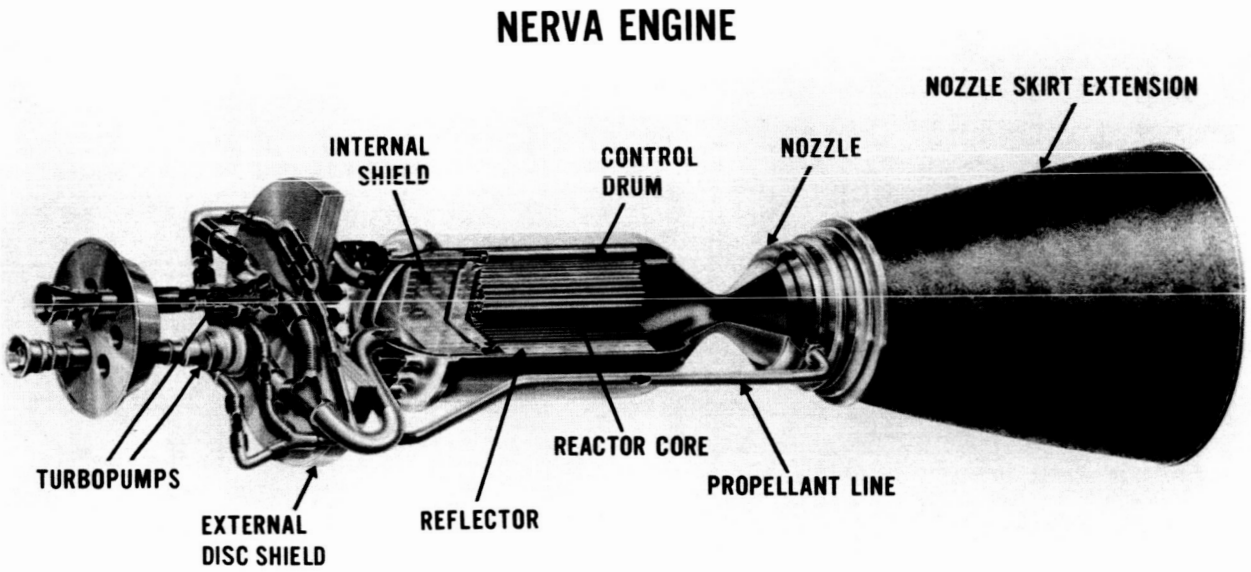


Image 59: The main components of a nuclear rocket engine with 75,000 pounds of thrust. The engine heated liquid hydrogen and exhausted it through the nozzle. (1970) (NASA C-2003-851)

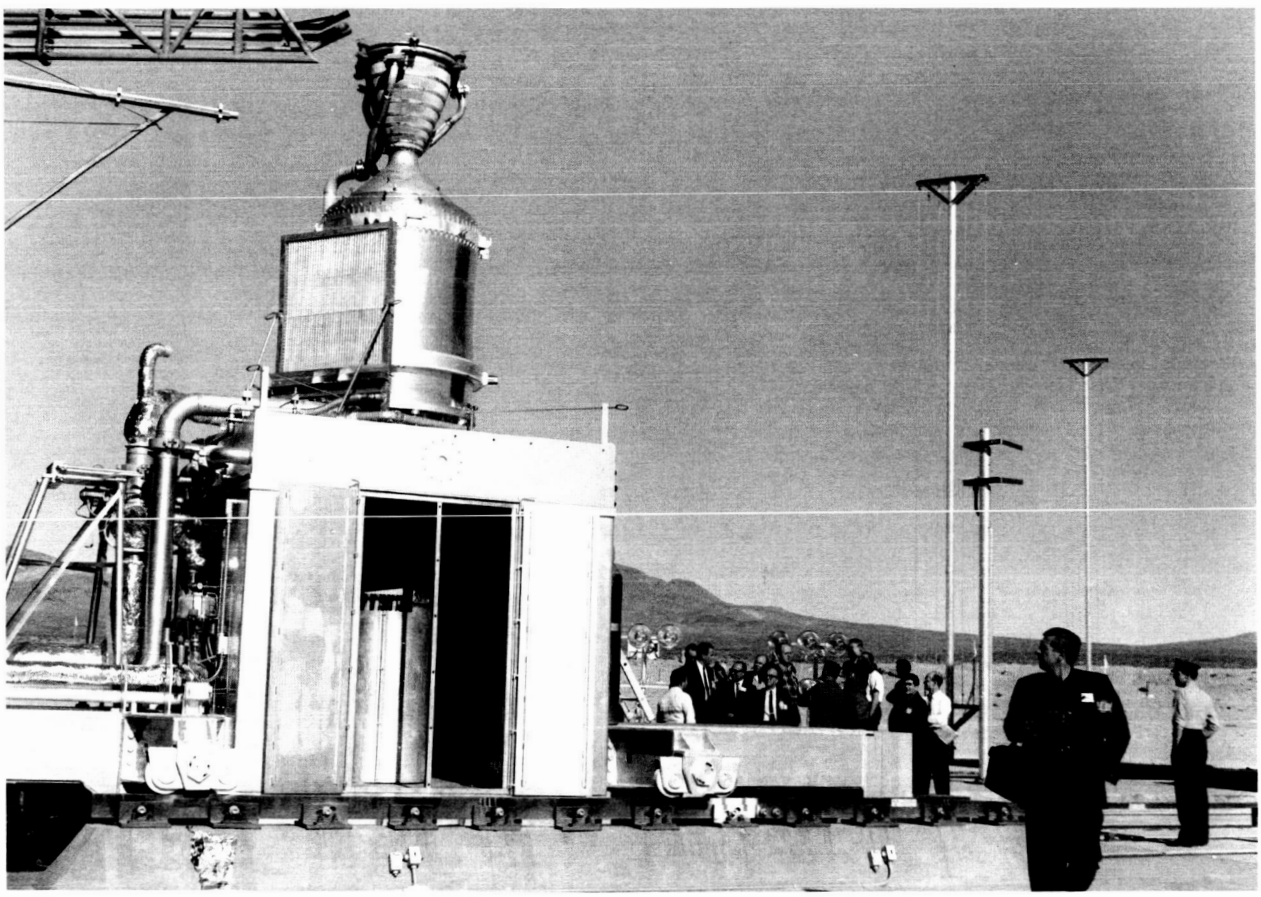


Image 60: Reporters and government officials examine the NERVA engine as it stands on its railcar test platform at Jackass Flats, Nevada. This engine was used for ground tests only. The nozzle on top released heated liquid hydrogen into the air and the engine remained fixed on a railroad track. (Harry Finger Collection)

Plum Brook's Nuclear Facilities

Los Alamos Scientific Laboratory, in association with the Air Force, initiated work on the nuclear rocket development program in 1955. At the beginning, its primary focus was to develop a potential missile application for use in warfare. In 1961 these efforts evolved into the Nuclear Engine for Rocket Vehicle Application (NERVA). In theory, nuclear rockets produced propulsion by directing cold liquid hydrogen into a hot reactor. This caused the liquid hydrogen to expand into a high-pressure gas, which resulted in a very high specific impulse that was roughly twice as powerful as that produced by chemical rockets. By exhausting the gas through a nozzle, engineers believed that between 50,000 and 70,000 pounds of engine thrust was possible. This thrust level was later greatly improved when on 26 June 1968, the Phoebus 1B Reactor was operated at 4200 megawatts, which produced 200,000 pounds of thrust. A second nuclear space application program called the Space Nuclear Auxiliary Program (SNAP) also began during this period. SNAP was developing a nuclear generator to provide electrical power for a spacecraft or satellite. By the mid-1960s NASA and the AEC had spent an accumulated $584.5 million on the two programs.[34]

One of the main concerns affecting both of these programs was how the materials used to build the spacecraft would withstand the damaging effects of radiation. The answer to this question became the focus of the experimental program initiated at NASA's Plum Brook Station. The chief of the reactor division, H. Brock Barkley, said, "Although many experiments have been run in other facilities in the past, they have not yielded the kind of information that NASA needs for space applications. That is why our job and our programs are so vital to NASA's application of nuclear power to space."[35]

After Congress cancelled work on the nuclear airplane, Plum Brook's mission was quickly revised to support work on the nuclear rocket. When Plum

Image 61: Jack Crooks (right) and Jerold Hatton work inside the reactor tank in preparation for the initial startup of the Plum Brook Reactor. They are inserting dummy fuel elements into the core as part of the final hydraulic testing. (1961) (NASA C–1961–56897)

Image 62: Harold Geisler takes the Plum Brook reactor critical for the first time on the evening of 14 June 1961. This first self-sustaining chain reaction was conducted at very low power. It wasn't until the following April that the reactor reached its full potential of sixty megawatts. By July 1963, the reactor had completed its first experimental cycle while critical. (NASA C-1961-56899)

Brook first reached criticality in June 1961, it joined 120 other research and test reactors already in operation across the country.[36] The only research or test reactor in the United States that was more powerful at the time was the Engineering Test Reactor in Idaho. As one of the most powerful test reactors in the world, the NASA Plum Brook reactor became a leader on the emerging nuclear frontier.

Reaching criticality for the first time was a momentous occasion. People gathered around the control room, either inside or looking through the large glass windows from the outside walkway. They all anxiously awaited the announcement that the reactor was finally critical. Reactor operator Clyde Greer said, "It was breathtaking to see one instrument especially." An ink line drawing represented the power level of the reactor. Everyone knew that once it reached criticality it would begin to trace a straight line. Once it did, Harold Giesler and Bill Fecych announced, "We're critical," and everyone began clapping and cheering.[38] Nuclear engineer A. Bert Davis recalled, "That was a special day when it went critical... I stood outside the glass looking in the control room observing what was going on. After it went critical we had a great party that night at a winery in Sandusky."[39]

Image 63: The lily pad area atop the reactor pressure tank. For over ten years, engineers subjected materials to radiation within this vast, cathedral-like containment vessel. In this picture, the shrapnel shields have been removed from over the pressure tank and the hatch has been removed and placed on the lily pad, revealing the open reactor tank. Monitoring was performed and experimental equipment was often assembled in this area. (1961) (NASA C-1961-55851)

Though the Plum Brook reactor went critical in 1961, it was almost two years before it operated at its full sixty-megawatt power capacity. While the power of the reactor was important, it was the neutron flux that was the main attribute that enabled advanced experimentation. Myrna Steele, the only woman physicist at Plum Brook, recalled, "The neutron fluxes and the neutron currents from the reactor at Plum Brook were among the highest in the world at the time that it was built and running."[40] The Plum Brook reactor was capable of producing average neutron fluxes of 4.2×10^{14} neutrons/cm^2-sec. This meant that the reactor could transmit 420 trillion neutrons through a square centimeter of space every second. In the United States, Plum Brook's performance was second only to the Engineering Test Reactor's 500-trillion-neutron flux. Worldwide, only the Dounreay Fast Reactor in Britain had a higher flux at the time, 2,500 trillion. Even though the Chalk River Laboratories reactor in Canada had a much higher power rating—135 megawatts versus Plum Brook's sixty megawatts—it was only capable of a 400-trillion neutron flux.

On 15 August 1963, the main reactor completed its first experimental cycle. During the experimental cycles, when the reactor was operational, a plume of vapor would drift over the reactor cooling tower. This plume became a

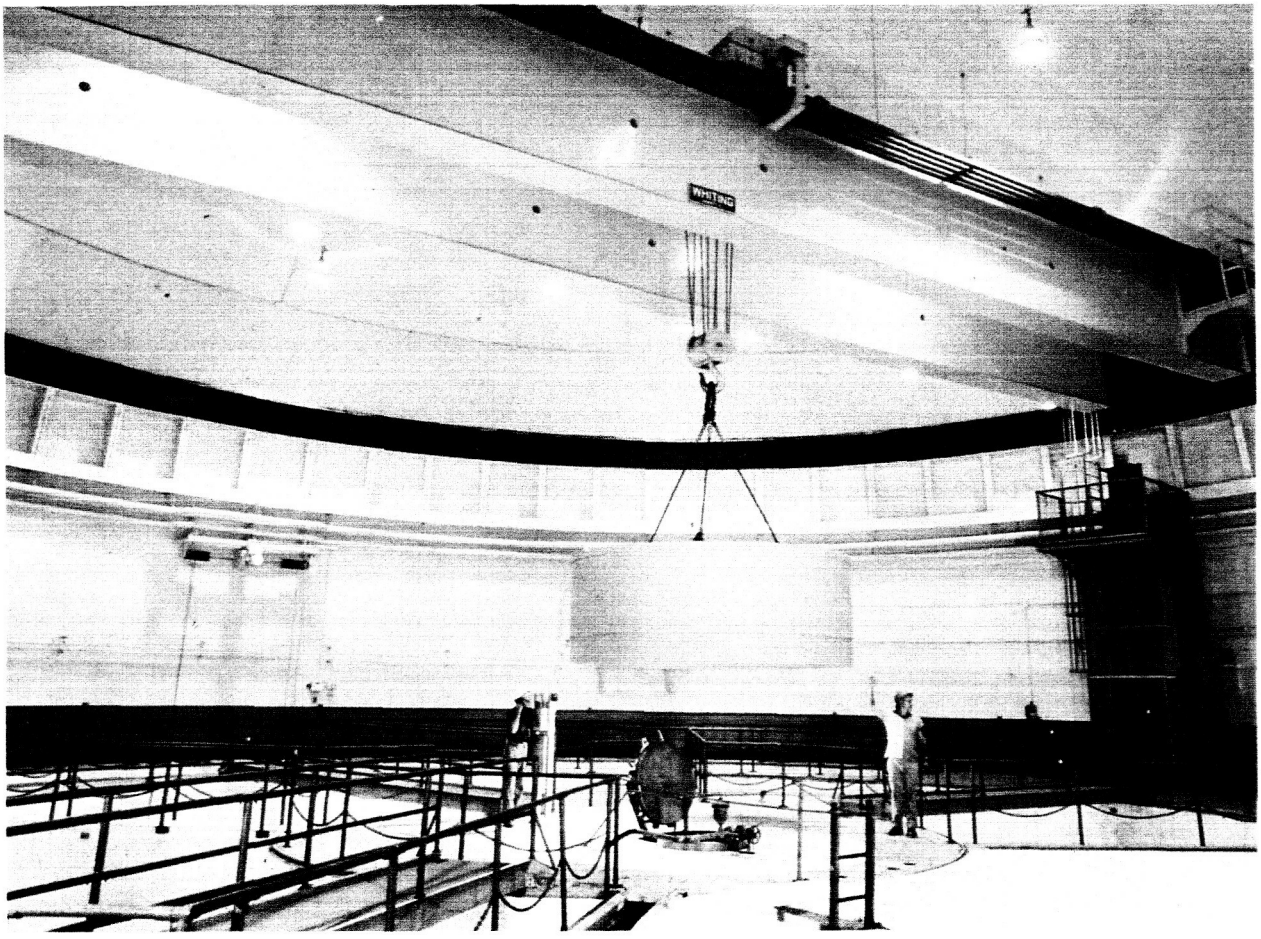


Image 64: Two men standing on the lily pad guide a crane to remove the third of three large, white, twenty-ton shrapnel shields that nest over the pressure tank. The shields were then stacked off to the side until it was time to reposition them on top of the pressure tank. Since the support beams could rotate 365 degrees, the overhead crane could reach any location in the containment vessel. The pressure tank hatch is open. (1959) (NASA CS-18228)

symbol to the reactor operators that their systems were operating normally.

That same year, Plum Brook received its AEC license for the Mock-Up Reactor (MUR). The MUR significantly increased Plum Brook's experimental capability and assisted in the overall experimental program by saving both time and money for the experiment sponsors.[41] Benefits included being able to make flux and reactivity measurements on the MUR without tying up the main reactor. The MUR also could help the engineers determine where the experiments should be placed, how much irradiation they would receive from the core, and how the experimental materials would affect the reactor. Maintenance on the MUR occurred monthly for all of its electronic systems. It first went critical at 9:30 p.m. on 10 September 1963, and was considered a "major milestone" for the facility.[42] Dick Robinson was the senior operator and supervisor, and Bill Poley operated the control panel.

In December 1963, the hot laboratory, headed by Robert Oldrieve, became fully operational. After materials were irradiated in the core, some of them were transferred via underwater canal to the adjacent hot laboratory building for examination, while others were transported in lead casks above the water. The radioactive materials also

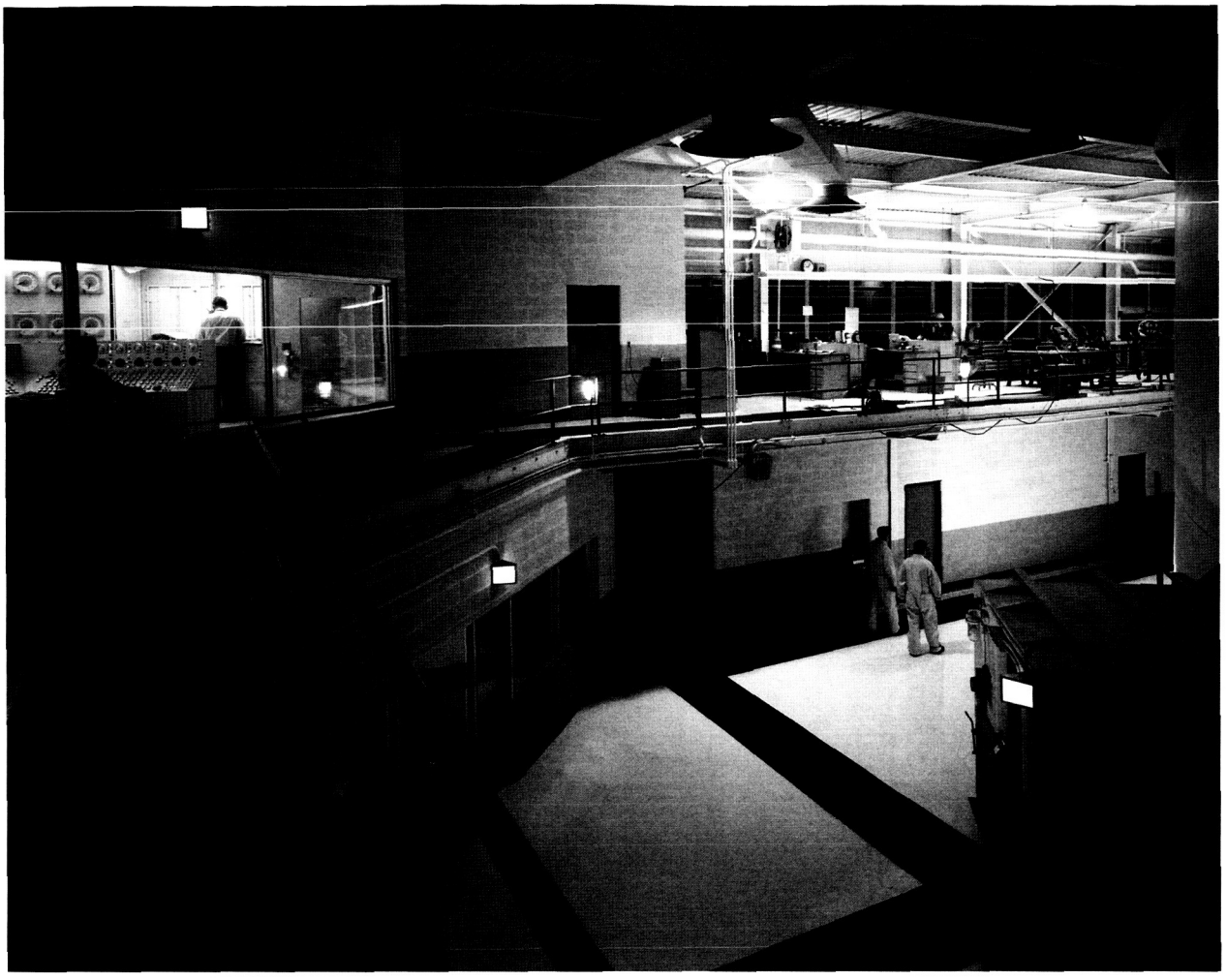


Image 65: The area just outside the containment vessel airlock (bottom right). The reactor control room on the second floor is visible to the left. The experiment control room is directly below it on the first level. On the second level to the right is a workarea that was later segmented and enclosed for office space. In this picture, three of the "Reactor On" signs are illuminated, indicating that the reactor is in operation. (1961) (NASA C–1961–55812)

The World's Most Powerful Test Reactors Prior to June 1961[37]

Rank	Country	Reactor	Critical Date	Power, kW
1	United States	Engineering Test Reactor, ETR	2 Sept 1957	175,000
2	Canada	Chalk River Laboratories, NRU	3 Nov 1957	135,000
3	Soviet Union	SM–3	10 Jan 1961	100,000
4	Soviet Union	27/BM	1 Jan 1961	70,000
5	Soviet Union	27BT	1 Jan 1956	70,000
6	Britain	Dounreay	1 Nov 1959	65,000
7	United States	SPERT–3, Phillips Petroleum	1 Jan 1958	60,000
8	United States	WTR, Westinghouse	1 Jan 1959	60,000
9	United States	NASA Plum Brook Test Reactor	14 June 1961	60,000

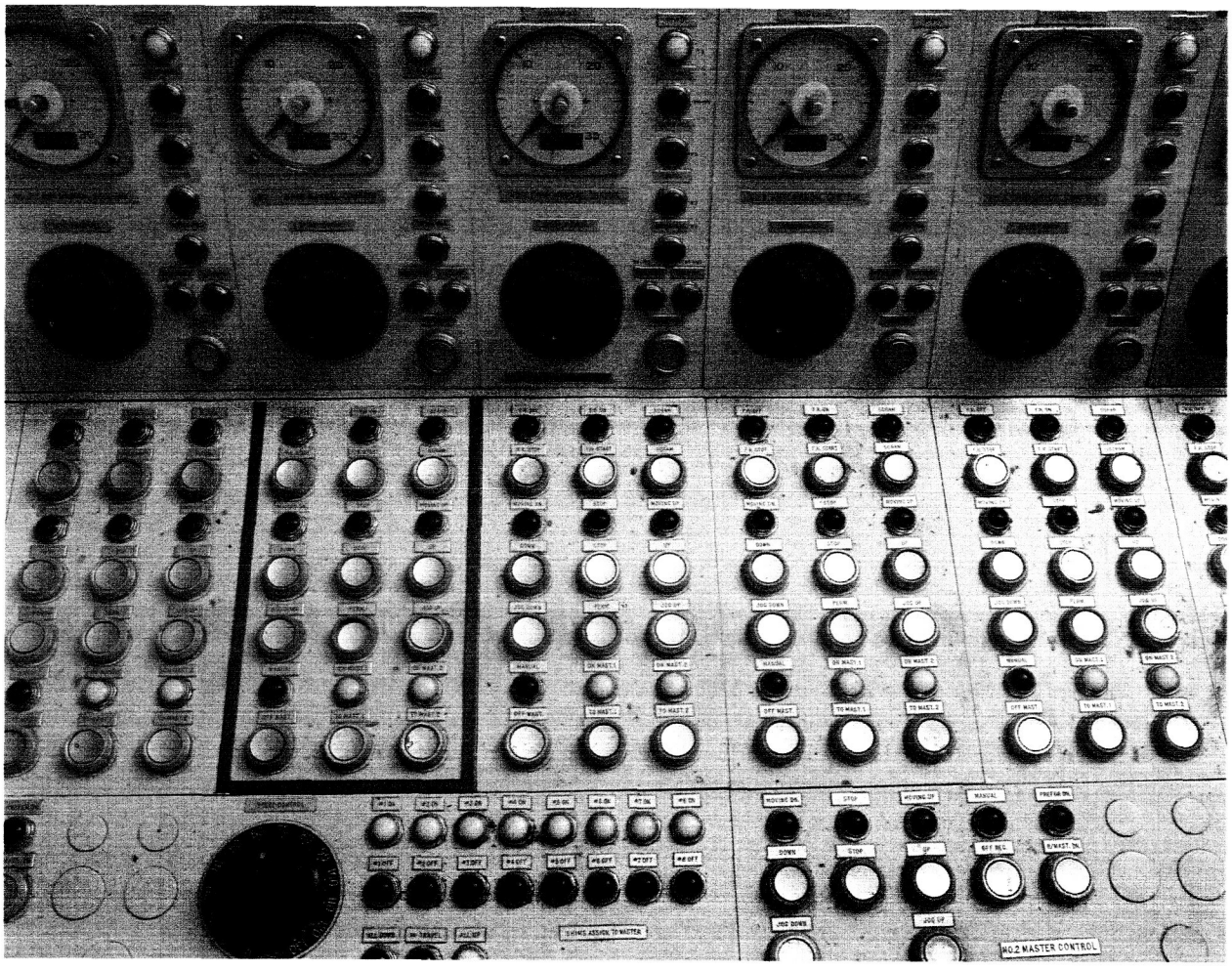


Image 66: This closeup of the right side of the control panel in the reactor control room shows the controls for the manual operation of the shim rods. Each rod has its own speed dial, meter, indicator lights, control buttons, and scram button. The buttons within the square on the left-hand side controlled the regulating rod that could activate a "junior" scram (a partial scram using only one regulating rod). It was designated within the box so that operators could quickly locate the rod's control buttons in case of emergency. The full scram buttons, which dropped all the control rods simultaneously, were set apart at the bottom of the console. (NASA C-2001-01229)

passed through a large room that shielded the rest of the laboratory from radiation. Then they could be examined in one of seven "hot cells." The walls of the hot cells ranged from forty-three to sixty-three inches thick and contained various tools and equipment to inspect and dismantle the experiments. In addition, "master-slave manipulators" allowed operators outside of the cell to work with materials. The Model A and Model D manipulators were both constructed by Central Research Labs, Inc., of Red Wing, Minnesota. Once the elements were disassembled, the irradiated materials were placed in rabbits (small metal capsules), which could be sent through pneumatic tubes to other laboratory rooms in the facility.

Public relations were very important, and most reactor operators considered it a "vital part of our job."[43] Tours were given to distinguished visitors from NASA, such as astronauts, and to the public and media. Some distinguished guests included Raymond Bisplinghoff (director of NASA's Office of Advanced Research and Technology), Harold Finger (manager of the Space Nuclear Propulsion Office (SNPO)), Glenn Seaborg (AEC chairman), the editors of *Nucleonics* magazine, officials from the Japanese Atomic Energy Commission, and professors from local universities who were considering the use of the reactor for their own experiments. In 1963, an aircraft landing strip was built in the southern portion of Plum Brook so

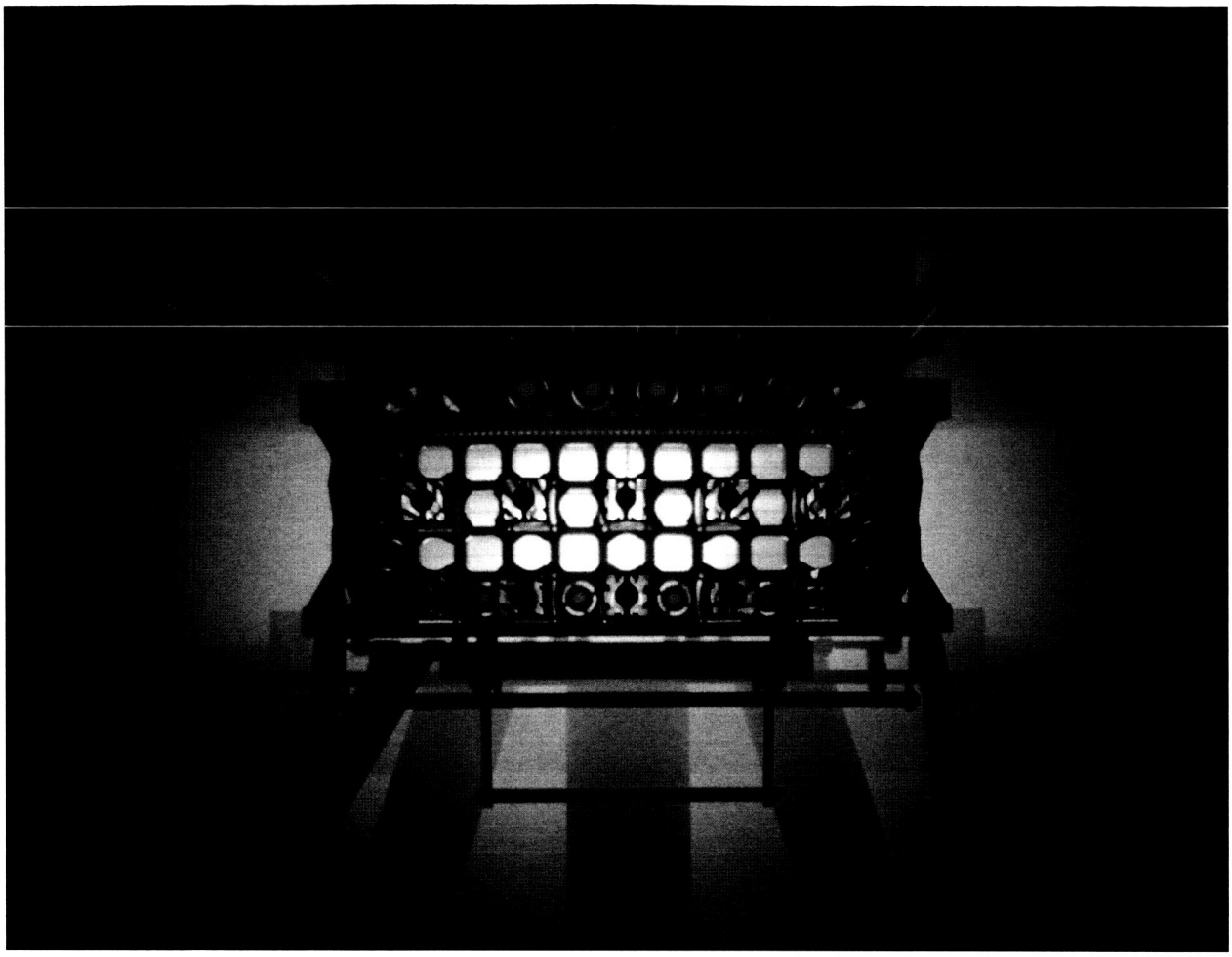


Image 67: During criticality, the Plum Brook Reactor core emitted an eerie blue glow known as Cherenkov radiation. This is common to all swimming pool reactors. The Cherenkov Effect is caused by high-energy beta particles moving at velocities faster than the speed of light in water. Pavel Alekseyevich Cherenkov first observed this phenomenon in 1934. Cherenkov's discovery helped with the detection of elementary particles and was significant for subsequent experimental work in nuclear physics and the study of cosmic rays. In 1958 he was awarded a Nobel Prize in Physics. (c. 1962) (NASA C-1996-03983)

that visits from important guests could be handled more efficiently. Frequent public tours were also given to demonstrate that the reactor was safe for the surrounding community, and also to let people know that the public funds were being properly utilized. After one tour for a Catholic school, Sister Mary Christopher wrote, "From the moment when the guards met us at the gate, all through the periods of explanation at the various stations, until the moment when we left, we were impressed by the willingness and competence of the personnel who helped to make our tour enjoyable and worthwhile."[44] General open houses were also held for the public. These were of tremendous interest to the community; over 1,600 people visited the reactor during an open house in October 1963. A speakers bureau was staffed by a group of reactor employees who traveled around to local schools and civic organizations talking about the reactor.

Though the reactor maintained its safety record, shutdowns, or "scrams," were relatively common and did not necessarily mean that there was a significant danger present. For example, in its second year of operation there were twenty-one unscheduled shutdowns.[45] These were most often due to operator errors, defective equipment, safety or control system malfunctions, and loss of

Image 68: Three technicians work on the core, inside the pressure tank, during one of the shutdown periods. Experiment cycles varied greatly. Some lasted months, while others only days. Each cycle consisted of two parts—the shutdown portion and the power portion. The shutdown periods were used to change fuel, perform maintenance, and work on experiments. (NASA C-1961-56897)

electrical power. Forced evacuations of the containment vessel were not common, but when they did occur they usually resulted from the presence of high levels of airborne radiation. Flooding within the vessel caused at least one evacuation. The majority of medical emergencies were common eye, hand, and bruise injuries. Individual employee radiation exposure was monitored daily and health physics managers used this information to keep track of monthly and annual accumulation. This radiation safety program ensured that employee exposures were kept below established safe limits. Throughout the Plum Brook reactor's entire history, there was never a case of personal injury or illness related to radiation exposure.[46]

However, accidents happened on occasion. For example, one evening during the second shift on 20 May 1964, three workers were removing control rod drive assemblies from the subpile room. Due to a simple mistake they were suddenly "drenched with primary water contaminating themselves and their protective clothing."[47] They were immediately taken to the decontamination shower and were closely monitored by health-safety personnel. After several showers they were cleaned of the radioactivity and airborne tests showed no other remaining contamination. These risks were considered worth taking because of the importance of the experimental program at Plum Brook.

Image 69: The Mock-Up Reactor (MUR) was a 100-kilowatt reactor installed in the reactor building to test experiments at low power before inserting them into the more powerful sixty-megawatt reactor. This allowed operators to determine the best location for the experiments and it also helped them understand the effects each loading scheme had on the neutron flux. Though much smaller and less powerful than the main Plum Brook reactor, the MUR required its own annual AEC/NRC license, and today has its own separate decommissioning plan. (NASA C-2001-01204)

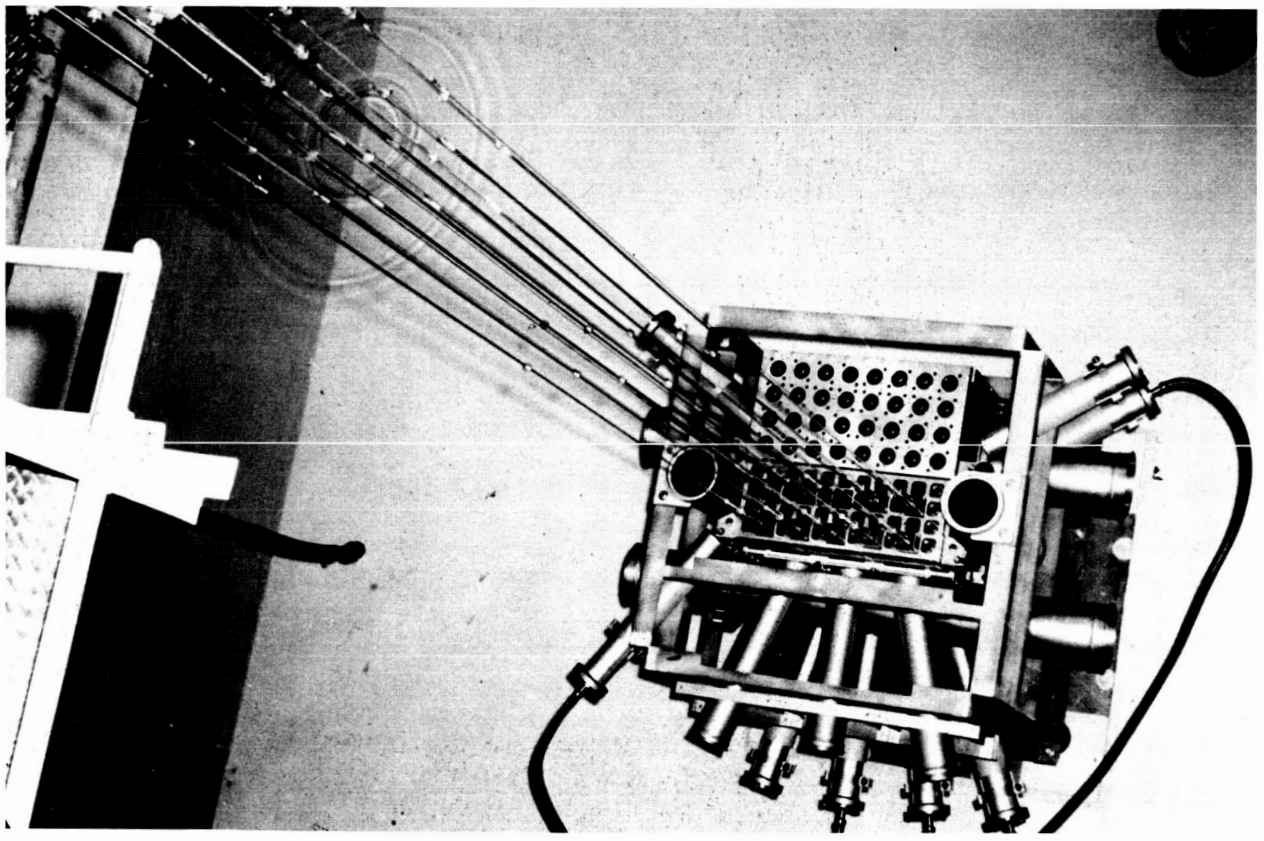


Image 70: The Mock-Up Reactor (MUR) core as seen from the control room. Since the MUR generated a very small amount of radioactivity, the "swimming pool" within which it was located provided sufficient shielding. A moveable bridge directly above the core allowed MUR operators to easily change fuel or manipulate experiments during shutdowns. (NASA PS63-0002)

Image 71: The control room for the Mock-Up Reactor was perched directly above its core. The large windows allowed the operators to view the controls and monitors, as well as the activity in the core below. (NASA PS63-0008)

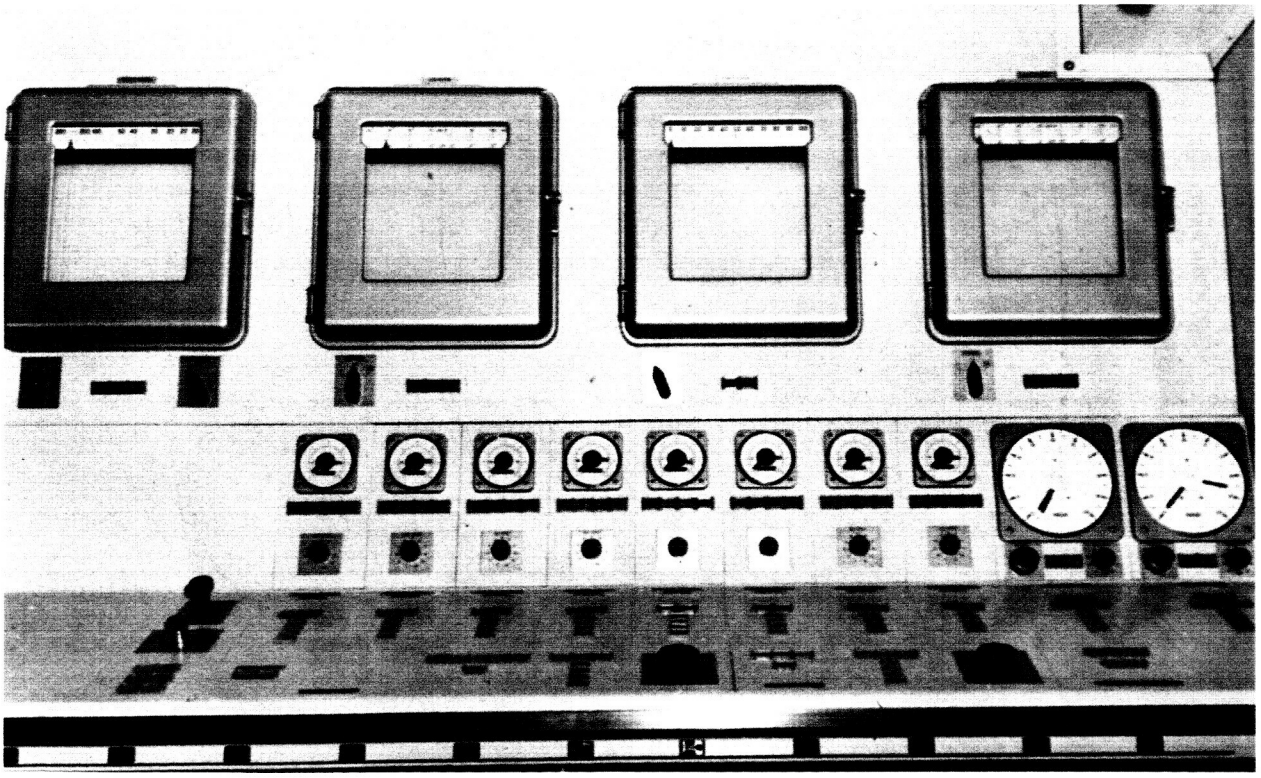


Image 72: Interior of the Mock-up Reactor control room. (NASA PS63-0005)

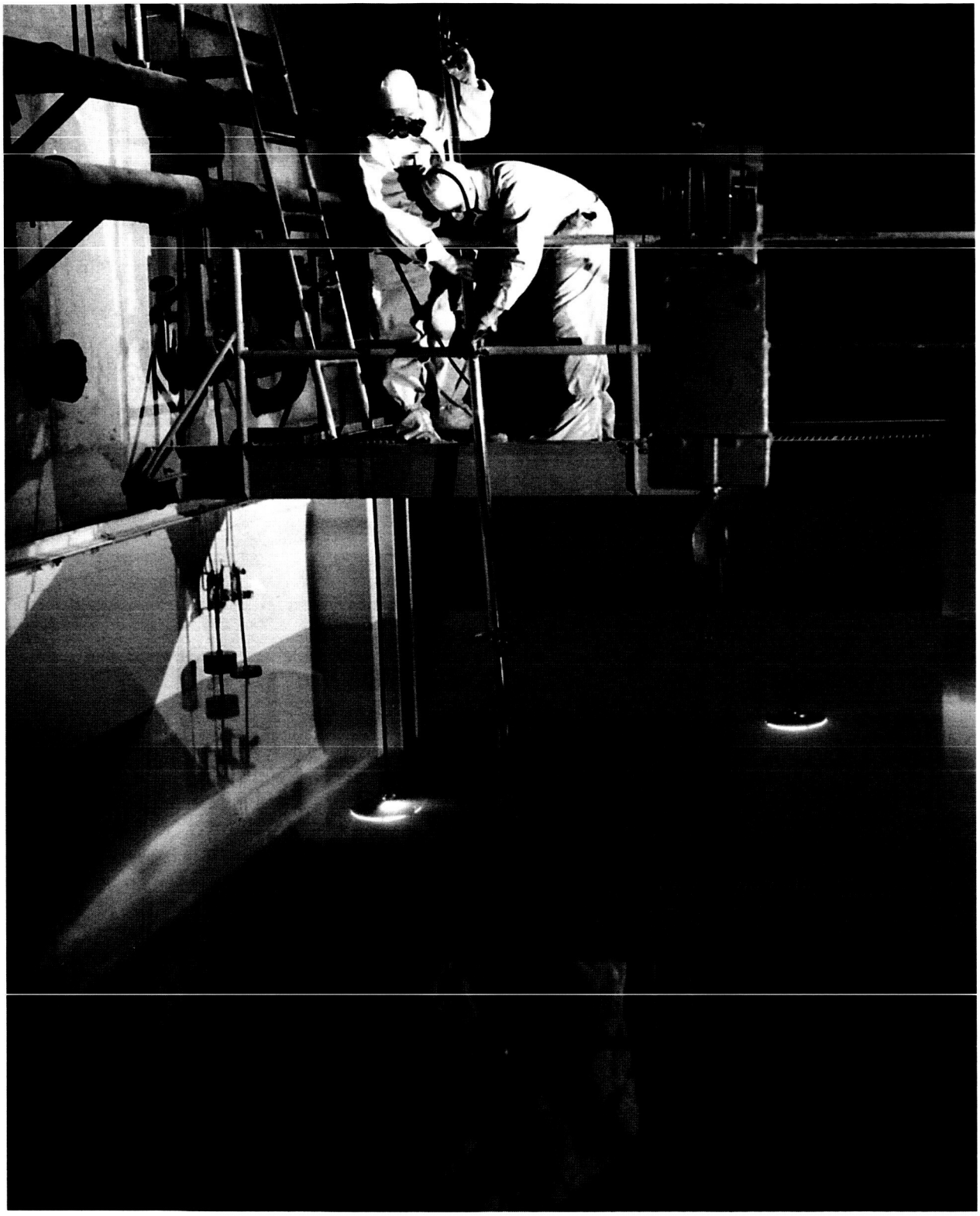


Image 73: Two technicians clad in anti-contamination clothing manipulate a shim safety control rod in a water canal in the hot laboratory. The twenty-five-foot-deep water provided shielding from radiation, yet still enabled visible contact with the research experiments. This water canal also allowed the underwater transfer of irradiated materials from the reactor to the hot laboratory for inspection. Moving materials by canal reduced the need for lead transfer casks, though they were still needed when the radioactive materials were taken out of the water. (1961) (NASA C–1961–55808)

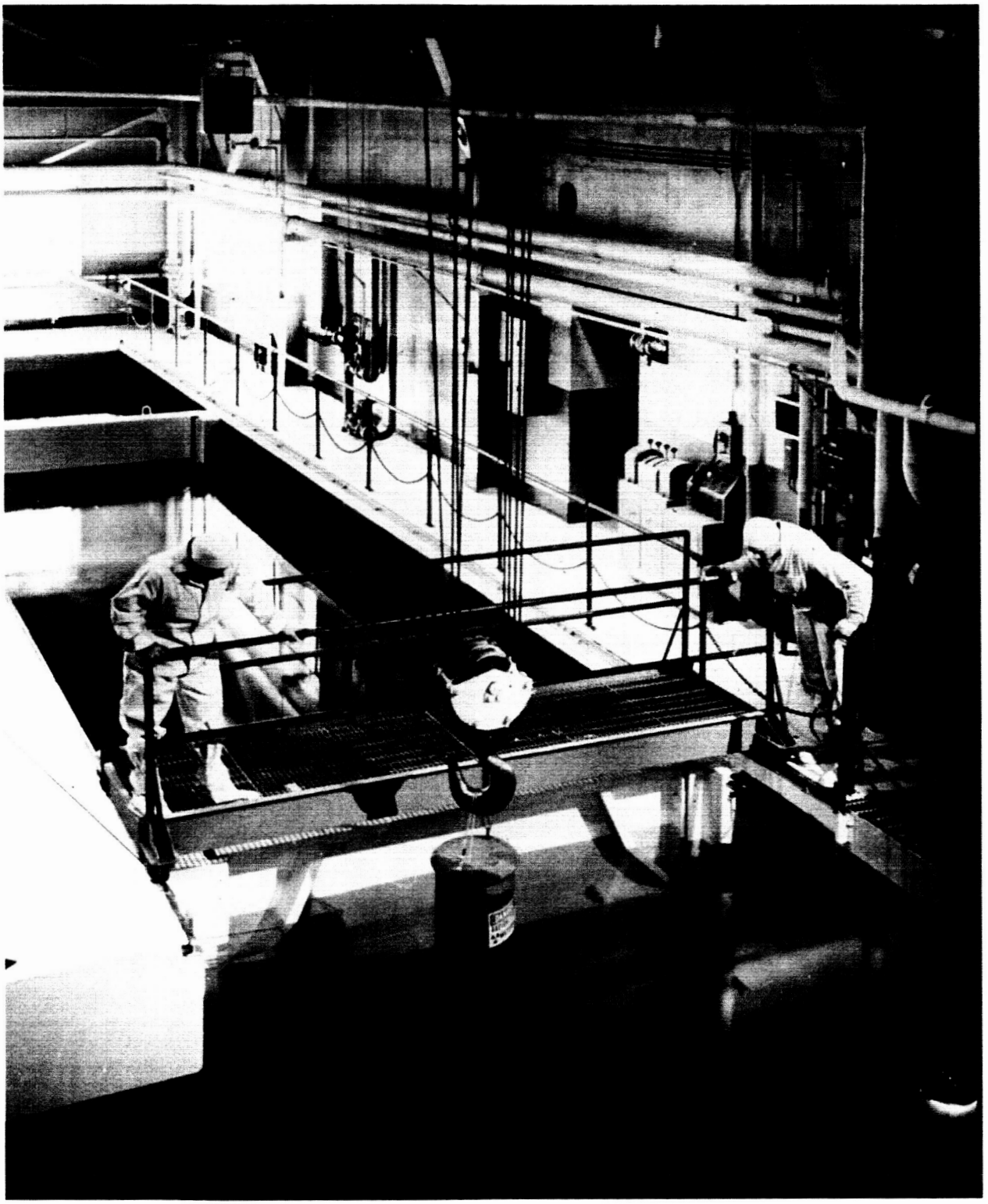


Image 74: Two Plum Brook employees use an overhead crane to lift a lead cask of low-level radioactive waste from Canal F. This was the first canal outside of the containment vessel. Canals G and H are visible behind the man standing on the bridge. The bridge was moveable so technicians could continually work above the objects as they moved through the canal system. The canal connected to the hot laboratory, which was adjacent to the south side of the reactor building. Radioactive materials were moved under water with vehicles, or remotely controlled cranes, between heavily shielded walls in the hot handling room and hot dry storage areas. Then they could be transferred to the hot cells. An eighty-ton lead door separated the hot handling room from the controlled workarea. (NASA CS-22209)

Image 75: A technician emerges from the rear of a hot laboratory cell in full protective gear carrying a "cutie pie" radiation detector. Another technician wheels open the massive sixty-three-inch-thick concrete door plug. (NASA CS–22203)

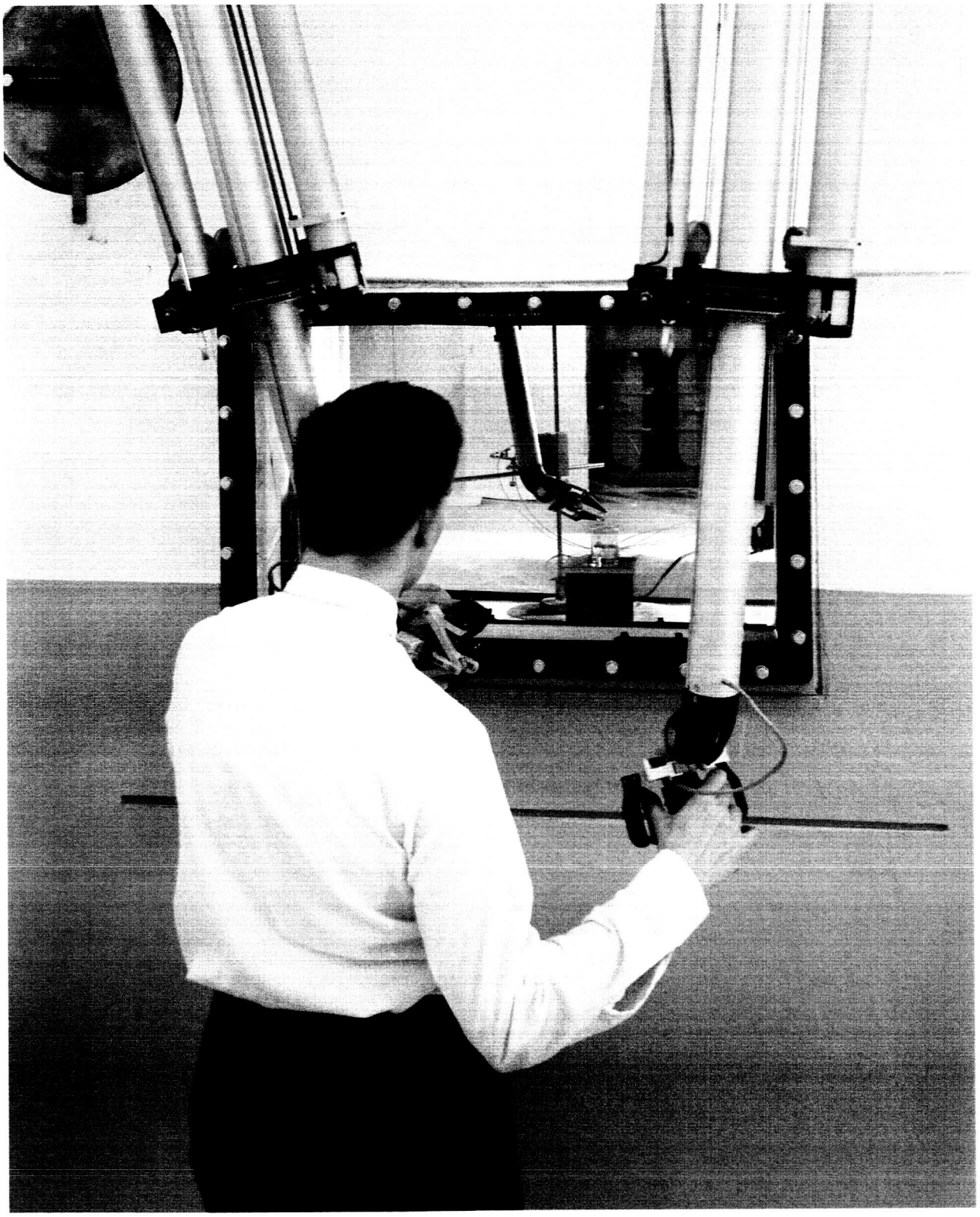


Image 76: Bob Oldrieve, a hot laboratory supervisor, uses manipulator arms to inspect radioactive materials within a hot cell. The pliers-type "hand" is visible inside the window. Operators became so skillful in operating the manipulators that some were even able to thread a needle with them. (1961) (NASA C-1961-55638)

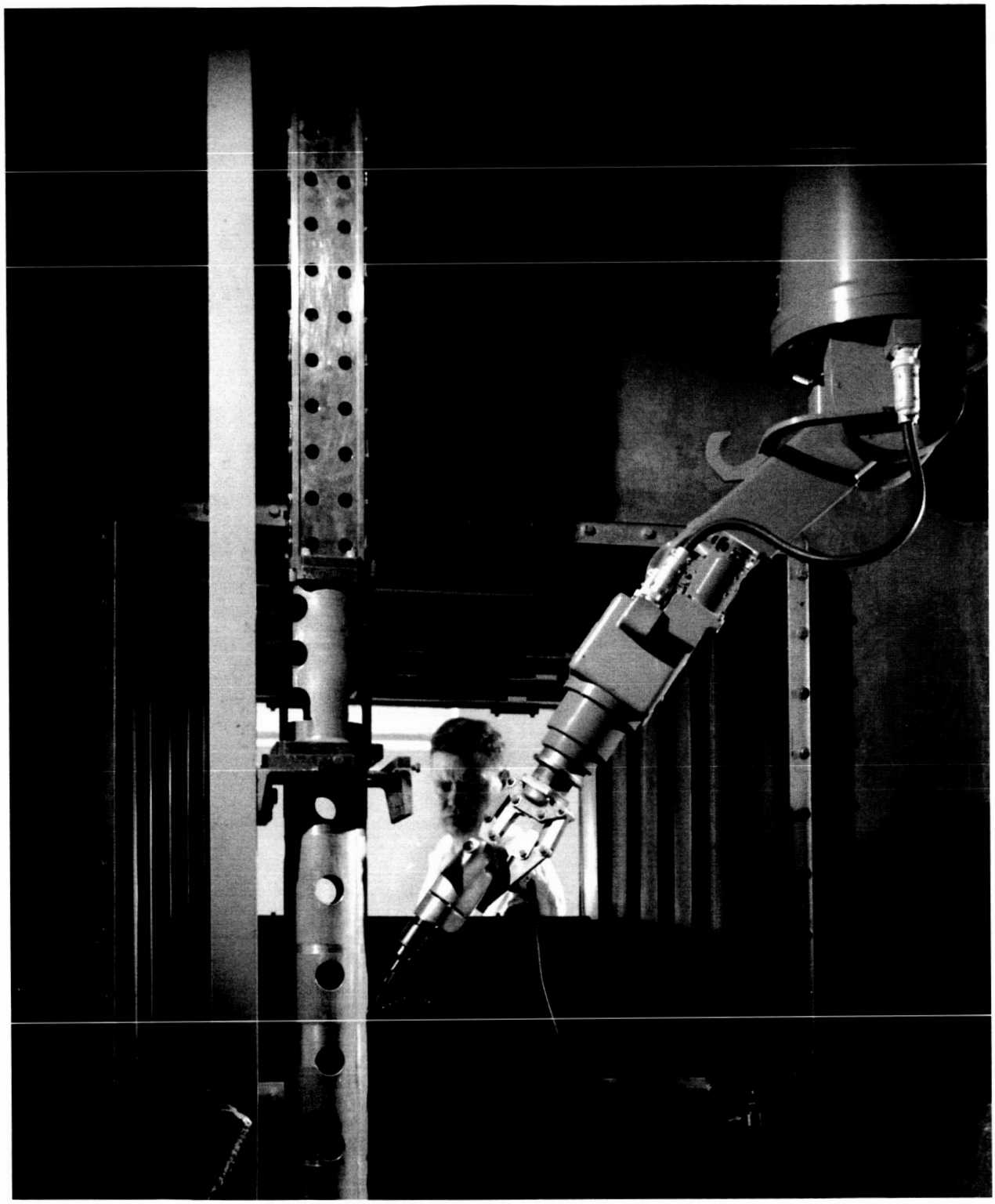


Image 77: View from inside a hot laboratory cell looking out. The manipulator arm is in the foreground; the engineer behind the glass, Dan Gardner, is operating it. A fifty-two-inch oil-filled glass window protected the operator from the radiation. The oil eliminated all of the window's distortion when looking through it. There were seven interconnected hot cells at Plum Brook—each with its own function. Cell 1 was over twice as large as the others. It was used for dismantling experiments when they entered the hot laboratory. Cell 2 had an engine lathe to machine materials. Cell 3 was a tensile testing facility with two sets of manipulator arms. Cell 4 was a preparatory area for Cell 5, where a variety of metallographic testing equipment was housed. Cell 6 was used for chemical analysis. Cell 7 had X-ray diffraction and analysis machinery. Each cell had filtered air, water, special vents, an intercom, and floor drains for liquid waste effluent. (1961) (NASA C–1961–55800)

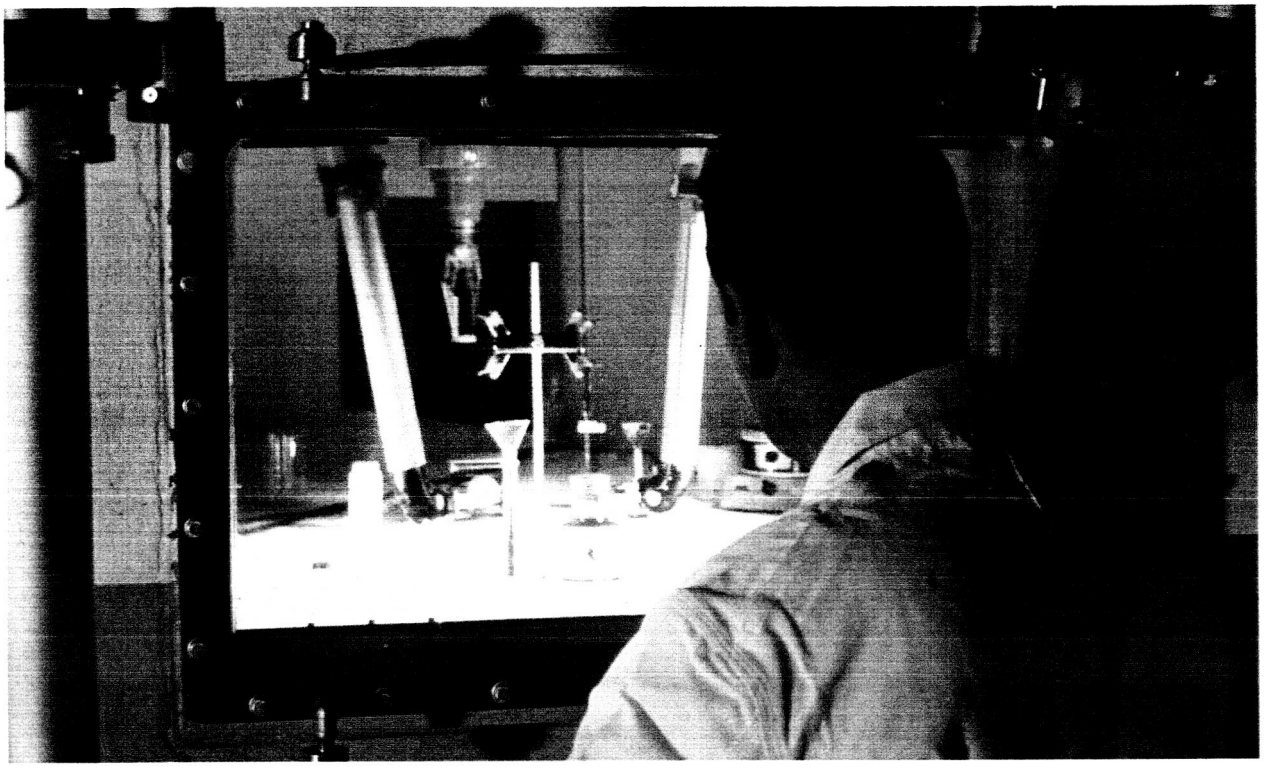


Image 78: View into a hot laboratory. Technician Dan Gardner examines irradiated materials using remotely controlled manipulator arms from behind protective walls and shielded windows. (NASA CS-22201)

Image 79: The hot laboratory's safe workarea. Operators are using manipulator arms to work with irradiated experiments in the cells. The hot lab also contained an office, manipulator repair shop, and a decontamination room that connected this "clean" operating area with the radioactive area behind the cells. (NASA C-2003-839)

Image 80: A health-physics technician uses a hand-held "cutie pie" radiation detector to check equipment for contamination. These detectors allowed technicians to quickly monitor specific areas or equipment. They worked in conjunction with the permanent systems that constantly monitored radiation levels throughout the facility. (NASA C–2003–840)

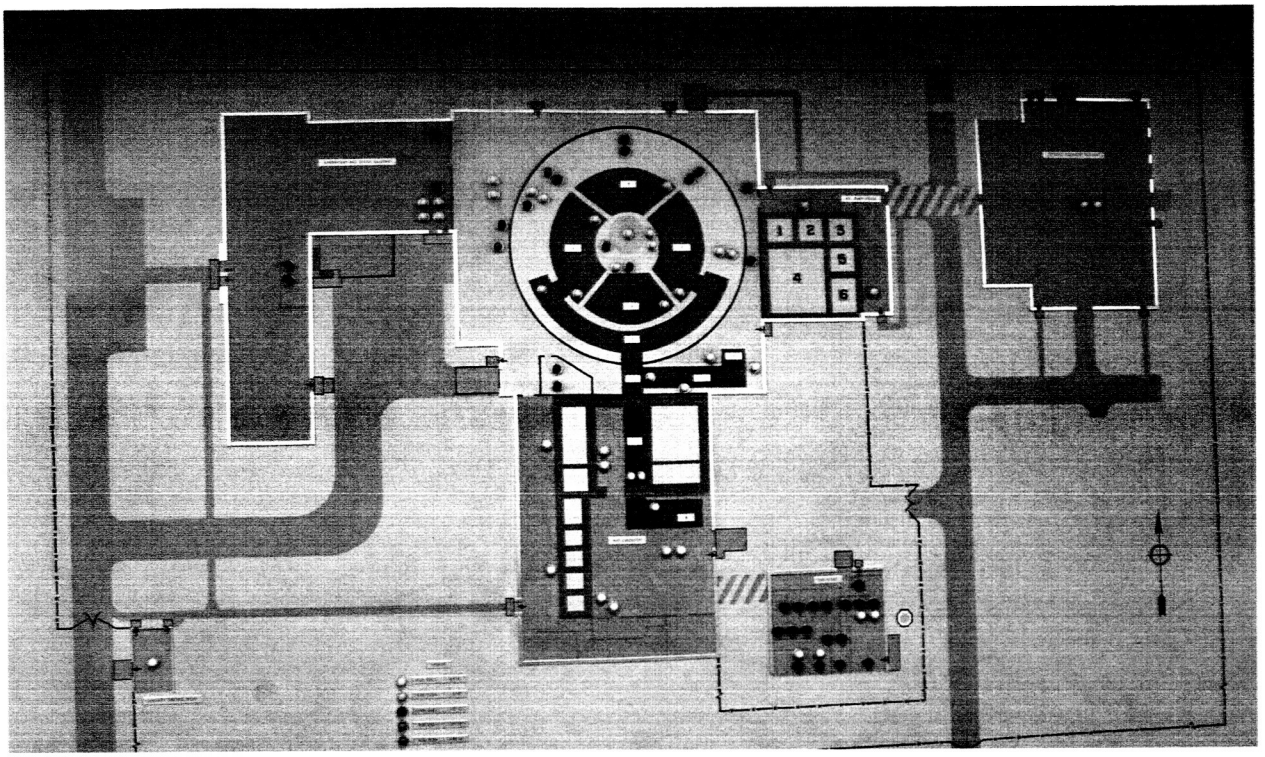


Image 81: Identical Remote Area Monitoring System (RAMS) detector location panels, found in both the health-safety operations office and the reactor control room, and other monitoring equipment allowed operators to monitor radiation sensors located throughout the facility and to scram the reactor instantly if necessary. The color of the indicator lights corresponds with the elevation of the detectors in the various buildings. The reactor could also shut itself down automatically if monitors detected any sudden irregularities. (2001) (NASA C-2001-01150)

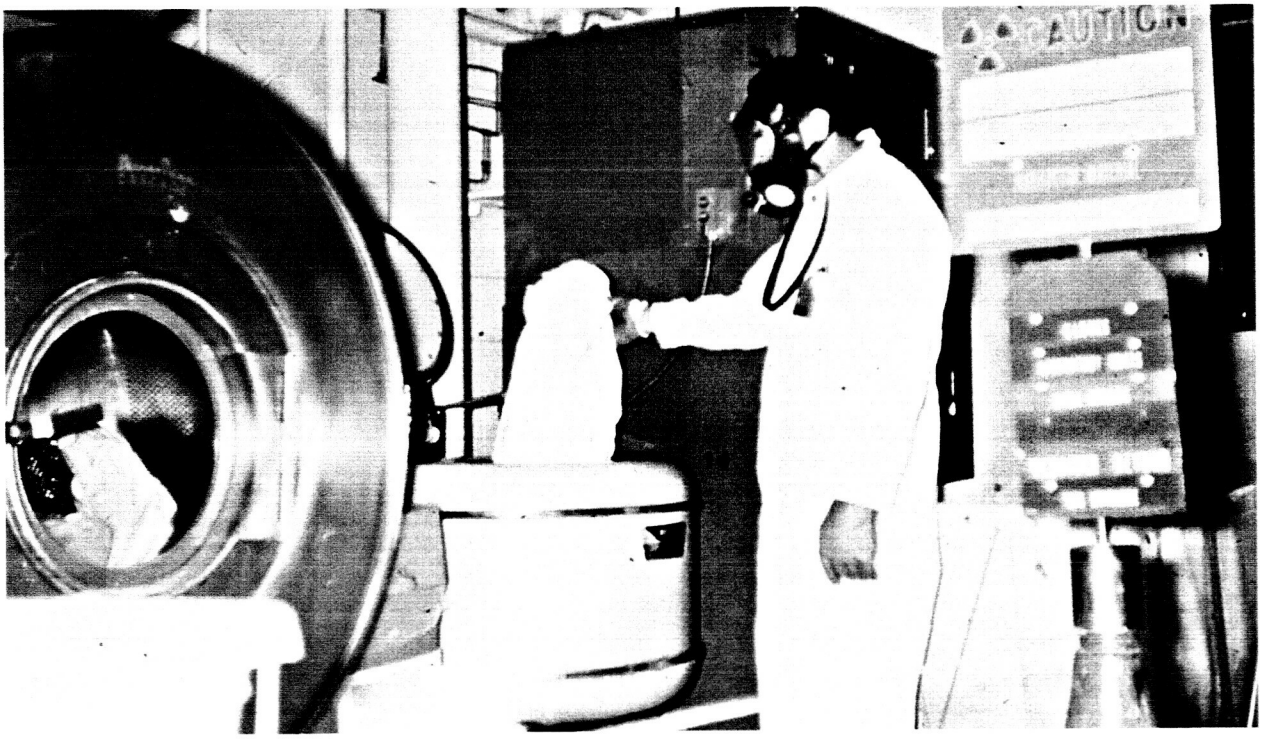


Image 82: A Plum Brook technician wearing protective clothing and a mask washes contaminated clothing. The clothing was worn again after it was decontaminated and laundered. The wash water had to be treated as radioactive waste. (2001) (NASA C-2003-841)

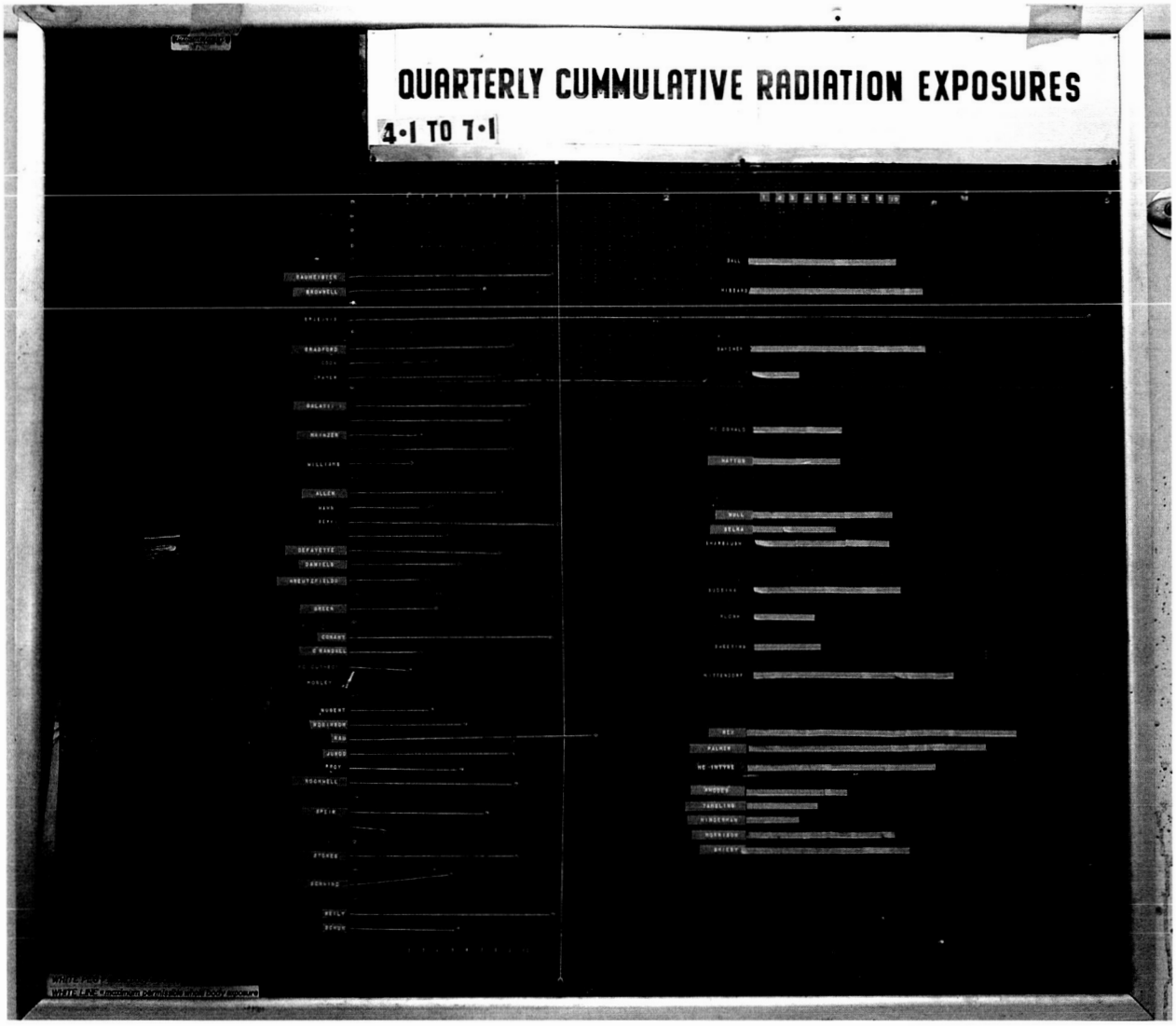


Image 83: This board in the health-safety operations office was updated by health-physicists with data from daily pocket ionization dosimeters and other monitoring instruments to ensure that no one exceeded the legally permissible radiation exposure limits. Strict limits were imposed on the amount of radiation that employees could be exposed to over time. These limits were far below the levels that were considered to cause health risks. All personnel assigned to Plum Brook Reactor Facility were monitored for radiation exposure on a continuing basis by utilizing film badge dosimetry. The frequency of the individual readouts varied from monthly to quarterly depending on the job assignment. Since there was an inherent delay in this technology, it became necessary to have current daily estimates of exposure for personnel who routinely entered radiation areas. Lifetime exposure levels were also closely monitored through regular bioassay samples. (NASA C-2001-01153)

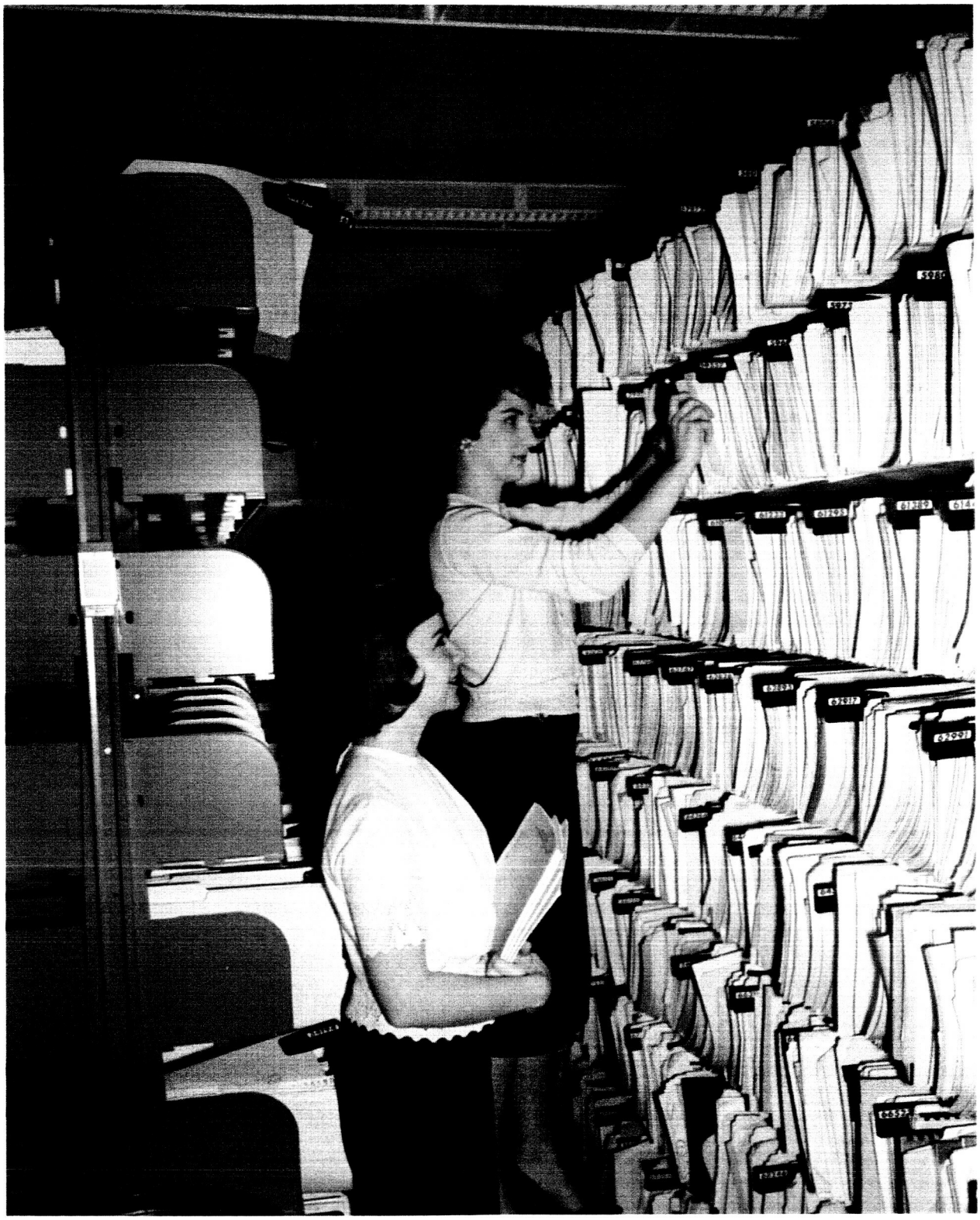


Image 84: Librarians manage files and books in the reactor library. Massive amounts of documentation were required to maintain licensing by the AEC. Unfortunately, many of these documents, including the experiment logs, photographs, and sponsor names, were destroyed. (1961) (NASA C–1961–56372)

Primary Document #7

The relationship between Lewis Research Center and Plum Brook was always a close one. During Cold War concerns about a potential Soviet nuclear strike on the United States, Plum Brook was also considered the primary evacuation facility for key Lewis personnel. The following excerpted document describes the plan.

From: Alan D. Johnson, Director, Plum Brook Station
To: Memorandum for the Record
Date: November 8, 1962

An informal discussion was held between Bob Gaines and All Herrmann of Lewis-Cleveland and J.R. Braig and the writer on 6 November 1962 at Plum Brook Station for the purpose of investigating the possibilities of using Plum Brook Station as an emergency command center for Lewis-Cleveland in case of enemy attack.

For purpose of discussion the emergencies were divided into three general categories: (1) An evacuation caused by an air raid alert but followed by no attack and no damage, (2) An evacuation caused by actual attack where the damage to Lewis Facilities was considered reparable with research to be resumed within a year, and (3) An evacuation caused by an actual attack with substantial damage to the Lewis Facilities such that a very substantial rebuilding and rehabilitation would be required.

In the case of evacuation, approximately eight to twelve key Lewis-Cleveland personnel would evacuate immediately with their families to Plum Brook Station. If the evacuation is of the second type above, the first wave of Lewis-Cleveland people coming to Plum Brook would be handled in the same manner. Evacuation of the third type listed above was not developed in any detail.

The need for acquisition of food, drinking water, heating and sanitary facilities, bedding, etc. was discussed. It was also agreed that Plum Brook Station personnel would look into the cost for converting igloos into suitable temporary housing. The discussions above concerned themselves with the evacuation of Lewis-Cleveland personnel to Plum Brook Station but did not enter into the area of the evacuation of Plum Brook Station personnel to Lewis-Cleveland in the event of an air strike in the Sandusky area.

Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

NASA
Plum Brook Station

Sandusky, Ohio
November 8, 1962

MEMORANDUM for the Record

Subject: Emergency Evacuation of Lewis-Cleveland Personnel to Plum Brook Station

1. An informal discussion was held between Bob Gaines and Al Herrmann of Lewis-Cleveland and J. R. Braig and the writer on 6 November 1962 at Plum Brook Station for the purpose of investigating the possibilities of using Plum Brook Station as an emergency "command center" for Lewis-Cleveland in case of enemy attack.

2. For purposes of discussion the emergencies were divided into three general categories; (1) An evacuation caused by an air raid alert but followed by no attack and no damage, (2) An evacuation caused by actual attack where the damage to the Lewis Facilities was considered reparable with research to be resumed within a year, and (3) An evacuation caused by an actual attack with substantial damage to the Lewis Facilities such that a very substantial rebuilding and rehabilitation would be required.

3. It was estimated by Mr. Herrmann and Mr. Gaines that in the case of evacuation of type 1 above that approximately eight to twelve key Lewis-Cleveland personnel would evacuate immediately with their families to Plum Brook Station. Using a median number of ten with an average of four per family it was Plum Brook's opinion that these people could be housed in the homes of Plum Brook Station personnel and that office space could be provided using existing facilities.

4. If the evacuation is of the second type above, the first wave of Lewis-Cleveland people coming to Plum Brook would be handled in the same manner as above. The numbers of people would be the same. It was estimated that the second wave might bring the total number of Lewis-Cleveland personnel to approximately thirty-five. Office space for these people can be provided through use of current facilities but it appears unlikely that housing would be immediately available with Plum Brook Station families. Temporary housing should be provided at Plum Brook Station. No estimate was made for what would be the third wave and it is assumed that these numbers will be developed in the future.

5. Evacuation of the third type listed above was not developed in any detail however it is assumed that the first and second waves of type 2 should be provided for. In all of the discussions it was necessary to make some assumptions as to the availability of Plum Brook Station facilities and personnel. It is the opinion of the writer that if the utilities are still available at Plum Brook Station after such an emergency that some research would continue. If however, the utilities are not available, Plum Brook Station personnel could be turned to the task of setting up and sanitary facilities that would be required if all task force would be required. It was communications on services. It was personnel relatio

tion of LRC Pers to PBS, Page 2

s led to the estimate of thirty-five

inking water, heating and sanitary
was also agreed that Plum Brook Station
ting igloos into suitable temporary
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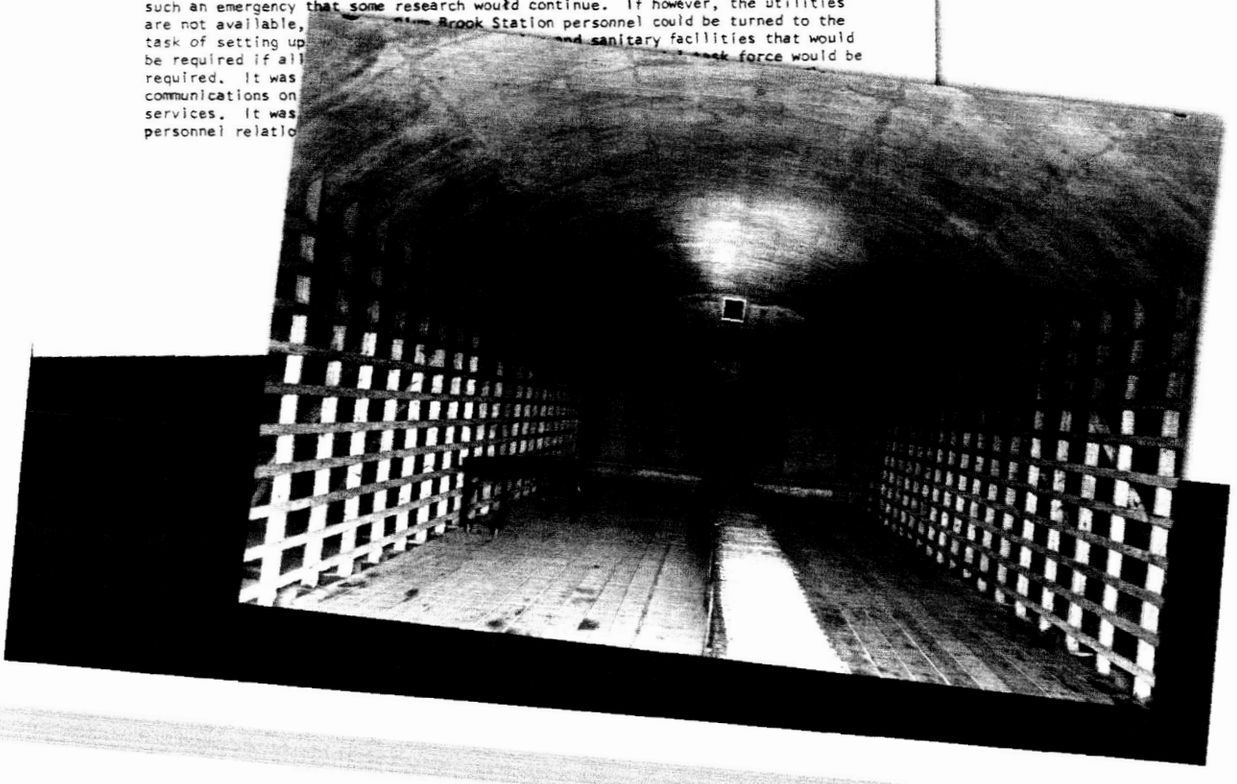
Alan D. Johnson
Director, Plum Brook Station



The Plum Brook Reactor Opens Its Doors

In an era of both paranoia and enthusiasm about the power of nuclear research, Plum Brook employees frequently held open houses for government officials, the media, high school students, and local families. The following photographic section illustrates some of these events.

Image 85: NASA Administrator James Webb (left) and Lewis Director Abe Silverstein (center, with glasses) peer into the reactor tank while visiting Plum Brook. (NASA C-1961-58735)

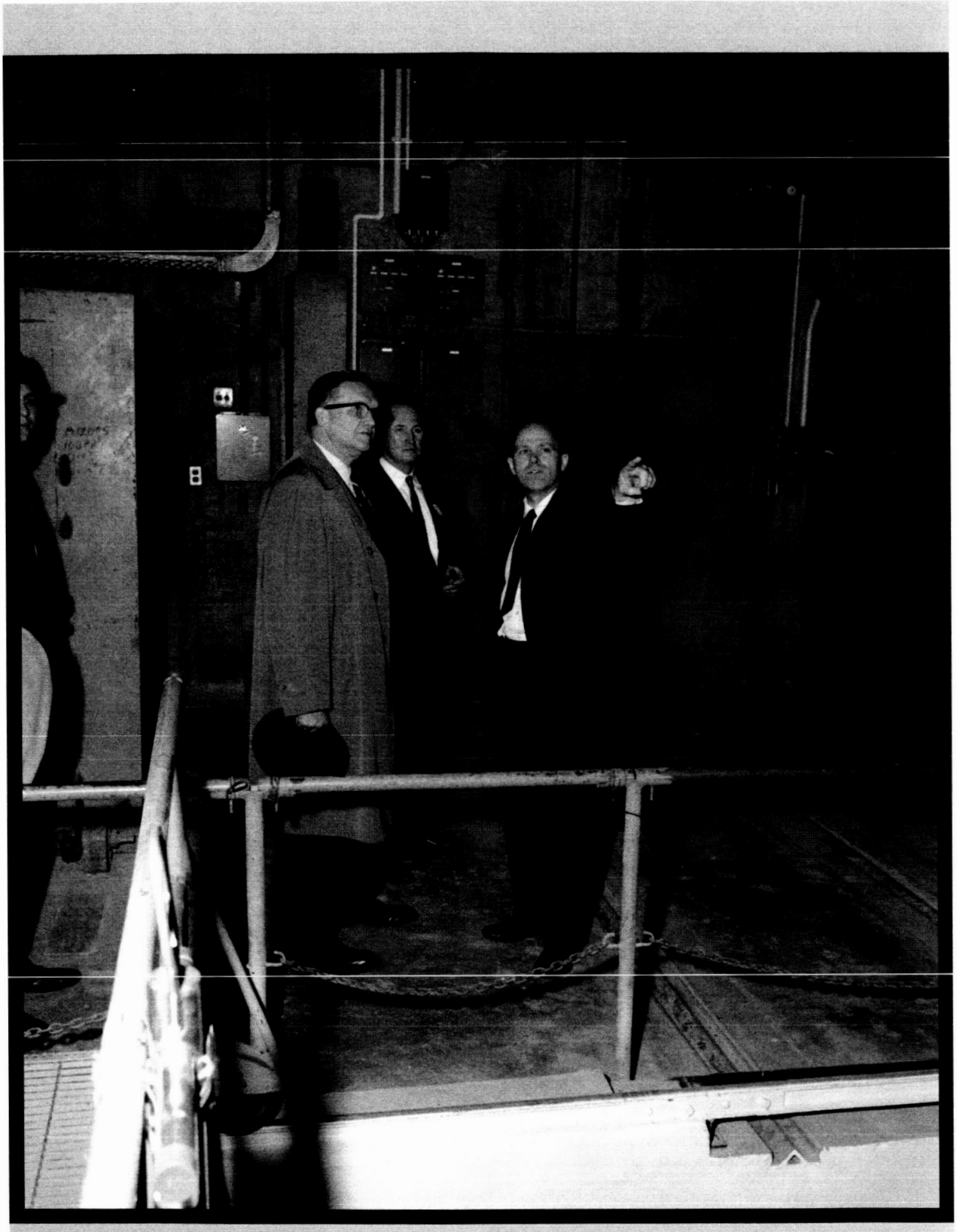


Image 86: Congressman Charles Mosher, a longtime Plum Brook supporter in Congress, and Ross Braig (center) are given a tour of the facility by Assistant Director Dr. John C. Evvard. (1961) (NASA C–1961–56466)

Image 87: Bill Kortier uses a sketch of the reactor facility on the blackboard and an aerial photograph of Plum Brook Station to familiarize reporters attending the March 1961 Media Day with the reactor operations just prior to the reactor going critical. Declassified information about the reactor facility was often supplied to the press. (1961) (NASA C–1961–56465)

Image 88: Reporters with cameras in hand are given a tour of the hot laboratory. (1961) (NASA C–1961–56468)

Image 89: Frequent tours were given to high school students and families from the local community to promote an interest in nuclear science and to dispel the anxiety people may have had about living next door to a nuclear reactor. (1962) (NASA PS62–1783)

Image 90: A Plum Brook representative explains the Plum Brook Reactor Facility to high school students. This model of the reactor building and the hot laboratory was intricately designed, down to the smallest detail—moveable manipulator arms, sliding canal doors, and even a blue light in the core. The model hung in the foyer of the reactor office and laboratory building during the reactor's operational days and is still on display at Plum Brook Station. (1964) (NASA C–1964–73677)

The Experimental Program

The Plum Brook reactor became an important tool for gathering the necessary data to construct a safe and efficient nuclear rocket and to design reactors to produce electrical power in space.[48] Scientists and engineers derived this data by developing an extensive experimental program. There were four basic types of experiments: nuclear rocket experiments, energy conversion experiments, basic radiation effects studies, and basic physics experiments. These experiments consisted of irradiating variously sized and shaped materials, components, and devices to determine how their behavior changed while being irradiated. After irradiation, through analysis in the hot laboratories, scientists examined how their physical properties had changed. The experiments did not always originate with NASA; they were frequently sponsored by outside contractors. The largest sponsors were Lockheed, Westinghouse, and General Electric, though these industrial organizations were carrying out the work on government contracts. They used Plum Brook to investigate the relationship between cryogenic temperatures and radiation, research the best materials for the NERVA and SNAP programs, and understand the behavior of thermionic diodes and fuel elements during and after irradiation (thermionics is the conversion of heat into electricity). In total, the Plum Brook reactor staff managed eighty-nine experiments during its years of operation.

One of the features that made the Plum Brook reactor unique was its cryogenic facilities. Nuclear rockets needed to not only maintain structural integrity in a radioactive environment, but also withstand the intense cold of both space and the liquid hydrogen propellant. Plum Brook installed special refrigeration capabilities that enabled experimenters to subject materials to radiation and cold at the same time. The first of these experiments was the Lockheed Cryogenic Experiment (62-01),[49] which determined how various metals reacted to cryogenic temperatures while in a radioactive environment.

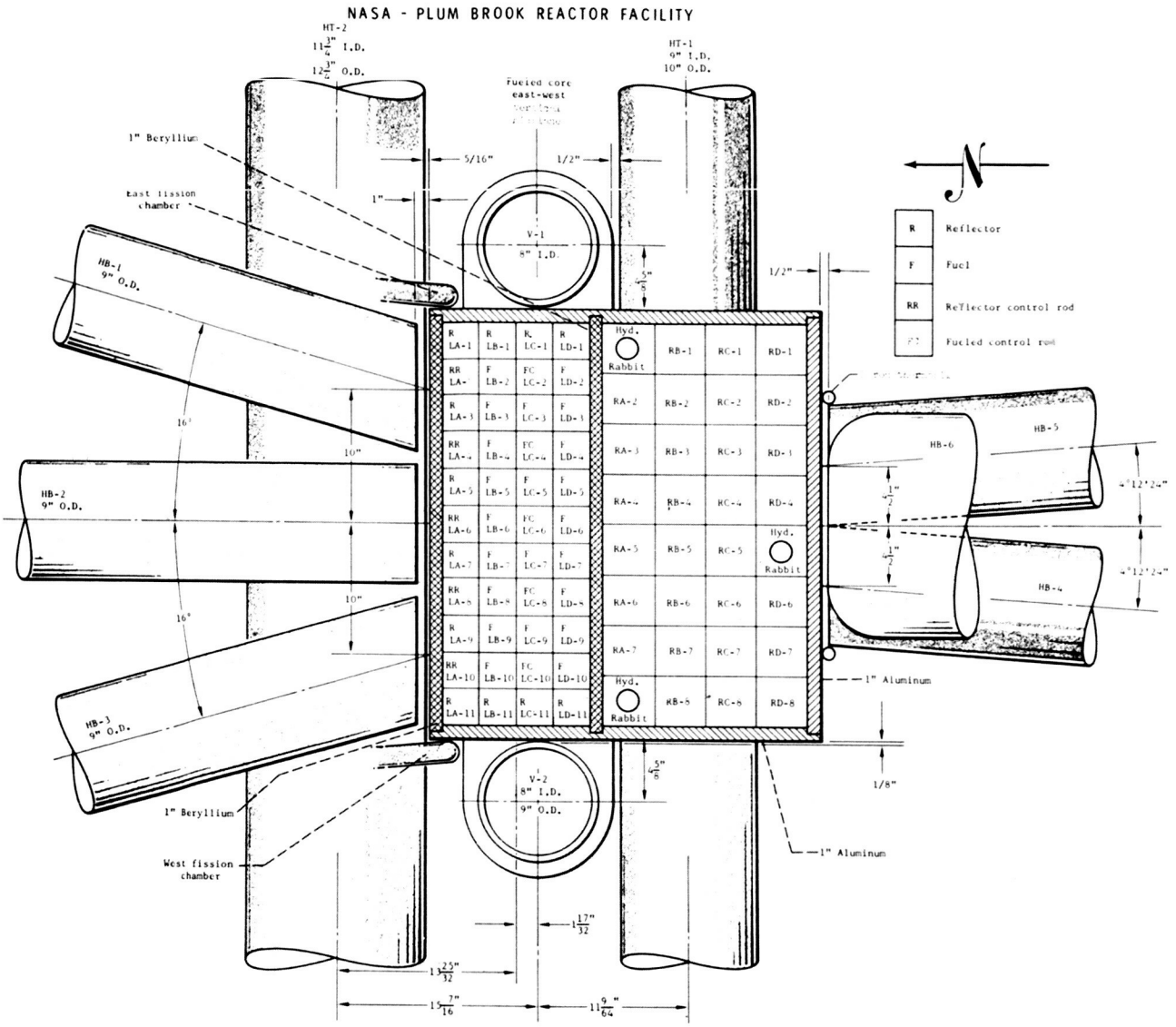


Image 91: This diagram shows the numerous "facilities" of the Plum Brook reactor core. Each of these was given a unique name (LA-7 or RD-3, for example). The facilities in the fuel area (left side) contained cadmium and beryllium moveable regulating rods around the exterior, three shim safety rods, and twelve fixed reflector plugs or experiments. The unfueled right side of the core box contained facilities for inserting up to thirty-two experiments. Three of these facilities (with circles) were hooked up to pneumatic rabbit tubes to provide quick insertion and removal of experiments. (NASA CS–46328)

Image 92: Hap Johnson (left) and H. Brock Barkley (right) examine a test specimen. It was designed to be inserted into the aluminum "rabbit," standing on end with its cap next to it. The rabbits housed the sample test materials. (c. 1970) (NASA C-2003-843)

A new $1 million cryogenic facility was built for the NERVA Components Irradiation experiment (62-16), and was about twenty times larger than the one used in the Lockheed Cryogenic Experiment. It had a twenty-kilowatt low-temperature helium refrigerator that could maintain a temperature between -409 and -39 degrees Fahrenheit. For the other extreme in temperatures, materials could also be irradiated at +3272 degrees Fahrenheit while in the reactor. It could test larger instrumentation components such as accelerometers, strain gauges, and displacement transducers, as well as smaller mechanical components like control drum assemblies, dynamic bearings, and molybdenum instrumentation tubes.[50] This was a unique capability at Plum Brook; few other nuclear facilities could run similar tests.[51]

Along with Lockheed, Westinghouse also played an important role in the NERVA program. The Westinghouse Astronuclear Laboratory was responsible for the nuclear reactor designed to go into the rocket, and the Plum Brook facilities were essential in helping Westinghouse scientists understand which materials were best suited for a radioactive environment. The Westinghouse NERVA Experiment (63-05) was a test to irradiate materials, especially transducers, for the nuclear rocket. The materials were placed in water-cooled capsules in the Plum Brook HT-1 facility. Samples

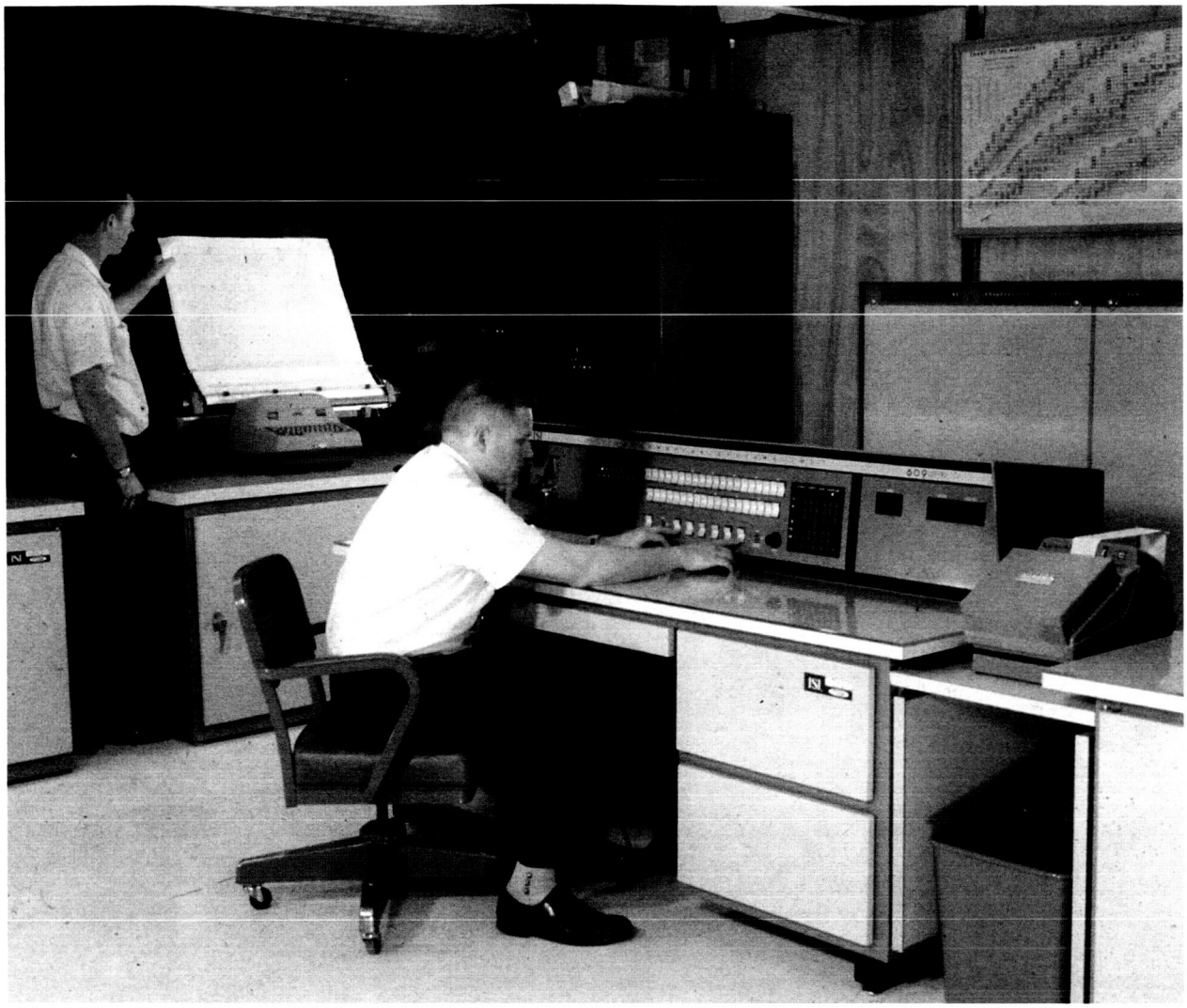


Image 93: The experiment control room, located directly below the reactor control room, contained various monitoring equipment. In this photo, Johnny Miller examines the Experiment Data Logging and Alarm System, which recorded all events during the operating cycles of the Plum Brook reactor in minute detail. Earl Boitel, seated, checks data input sources. (1964) (NASA P64-0713)

included instruments as well as complete component assemblies.[52] This experiment lasted for over three years. Westinghouse Refractory Fuel Compounds (62-15) was the first fueled experiment at the reactor, run in August 1964. The fueled experiment enabled irradiation of materials at high temperatures and high power for long periods of time. The ability to test fueled experiments was one of the major reasons that the Plum Brook reactor was constructed.

NERVA was not the only nuclear space initiative researched at Plum Brook. SNAP represented another significant application of nuclear power. It was hoped that the results from these experiments would help engineers design better circuits and other electrical equipment that could operate reliably and withstand the radioactive environment of a space reactor. Nuclear Electric Sub-Systems and Component Irradiation (63-09) explored the reaction of electronic equipment to neutron and gamma radiation for the SNAP-8 program. Radiation damage occurred every time that radiation interacted with matter. This phenomenon was explored in 1946 by Eugene Wigner; it became known as "The Wigner Effect."[53] What made this problem more difficult was that the damage occurred to the materials before any direct visual

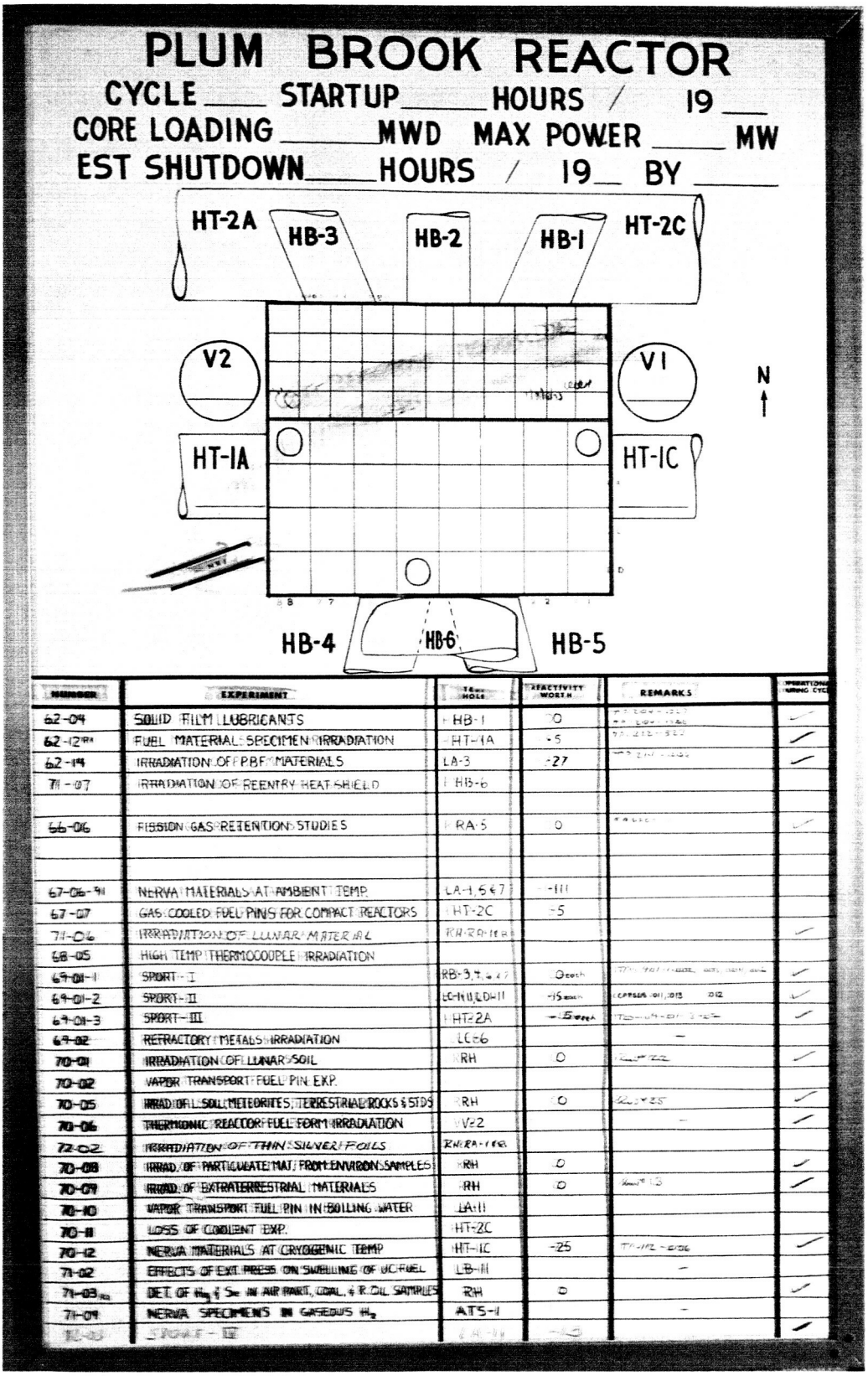
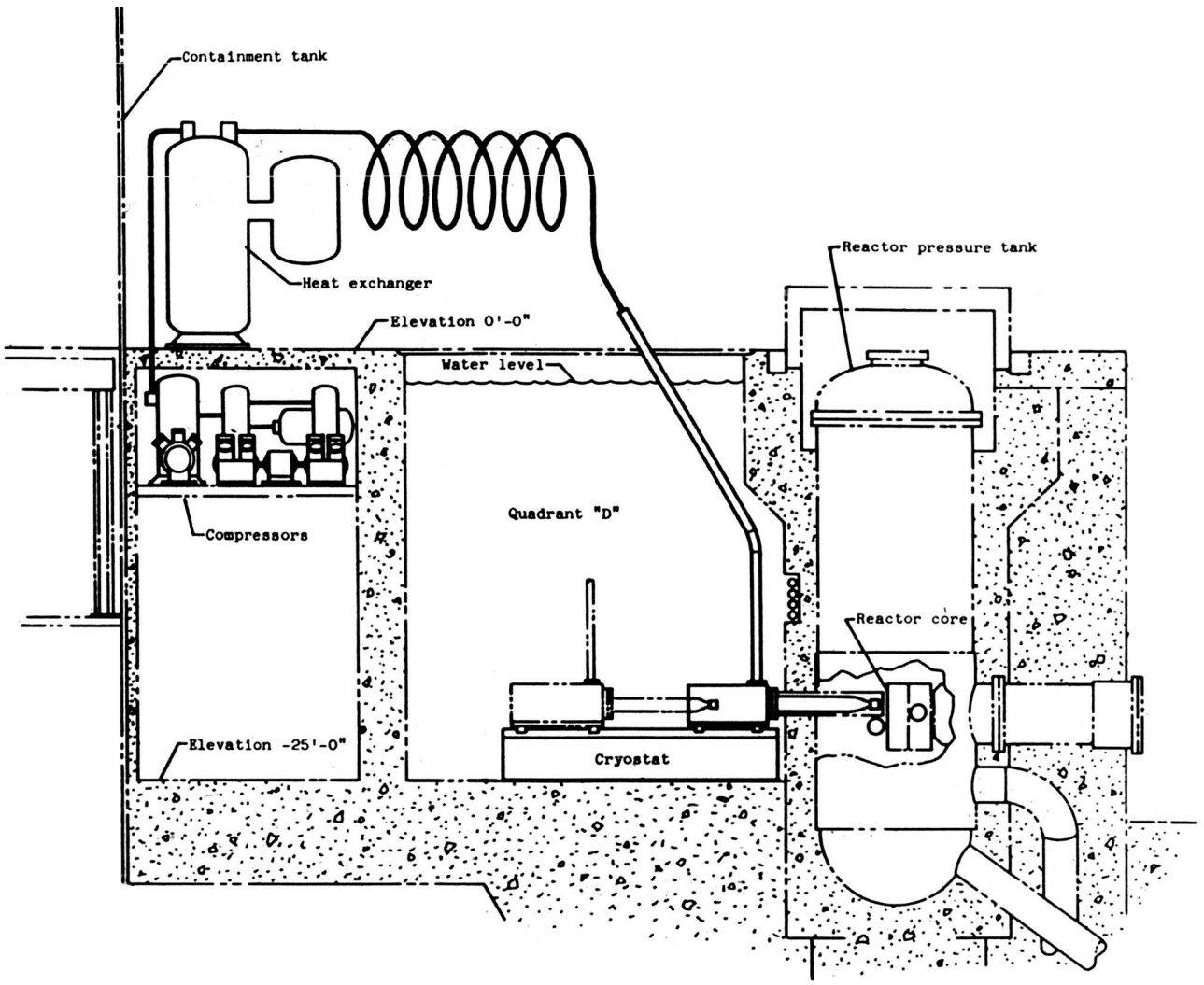


Image 94: This chart hung in the reactor building outside the experiment control room. It listed the experiments to be irradiated for each cycle and the through-holes, or access ports, to the reactor assigned to them. The core diagram also showed where the experiment was to be placed. The three circles in the lower portion of the grid represented the pneumatic rabbit facilities. (2001) (NASA C–2001–1258)



(a) Proposed arrangement of equipment within reactor facility.

Experiment on radiation effects on materials at cryogenic temperature.

Image 95: The HB-2 Cryogenic Experiment investigated the effects of low temperature and high radiation on various metals for potential use in space vehicles. The experiment consisted of a refrigeration system, a transfer system, and devices for measuring the strain resulting from radiation and temperature extremes. Four cryostats (or test loops) were used to measure tensile-fatigue compression. Each cryostat was six inches in diameter and nine feet long. One could be set up on the floor of Quadrant D, inserted into the core through the HB-2 beam port, and transferred remotely to the hot cave on the outside of the quadrant for removal of the specimen. (NASA CS-18942)

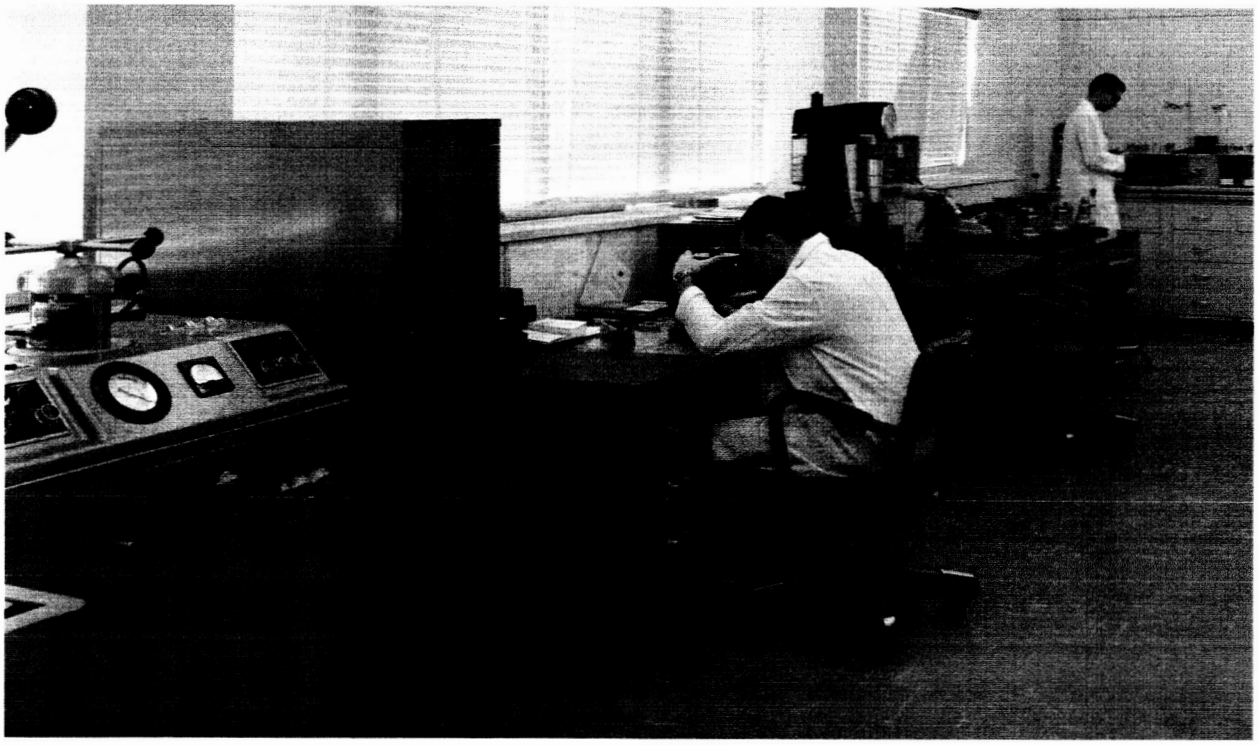


Image 96: Laboratory technician Allen Larkins (upper right) and engineer David Willinger (lower left) working in the metallurgical laboratory of the Plum Brook reactor. (1961) (NASA C-1961-55641)

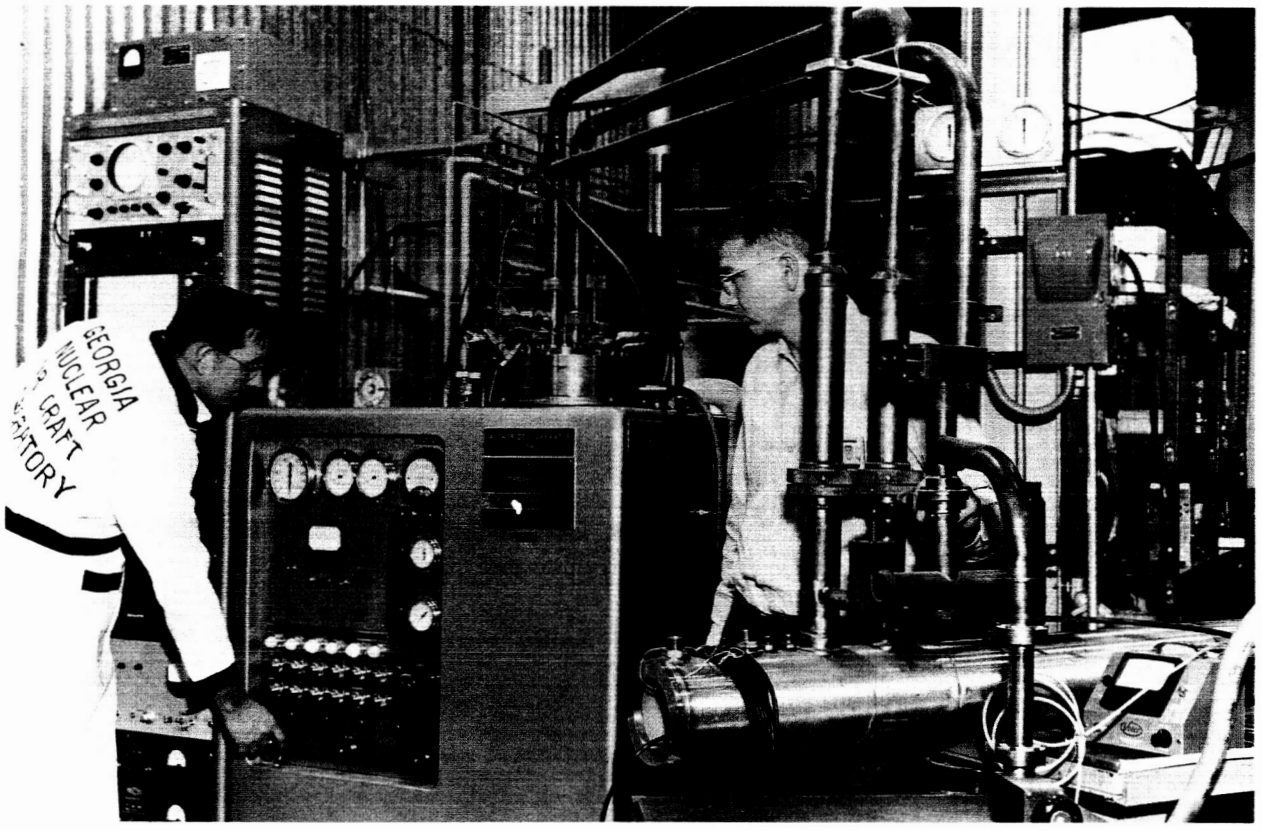


Image 97: Lockheed-Martin engineers make adjustments to the cryostat refrigeration machine that was being prepared for use in the Plum Brook Reactor Facility. The machine was used to test metals for their cryogenic resistant qualities. (January 1962) (Cleveland Public Library Photograph Collection, Ohio, Sandusky, Industry, NASA, Plum Brook Station)

Image 98: Astronaut Gordon Bean gets ready to insert the plutonium-238 heat source into the Space Nuclear Auxiliary Program 2 (SNAP-2) thermoelectric generator. Apollo 12 was the first mission to use the generators. This generator was capable of producing seventy-three watts of power for the Apollo lunar surface experiment package and had a lifespan of eight years. (1969) (NASA AS12-46-6790)

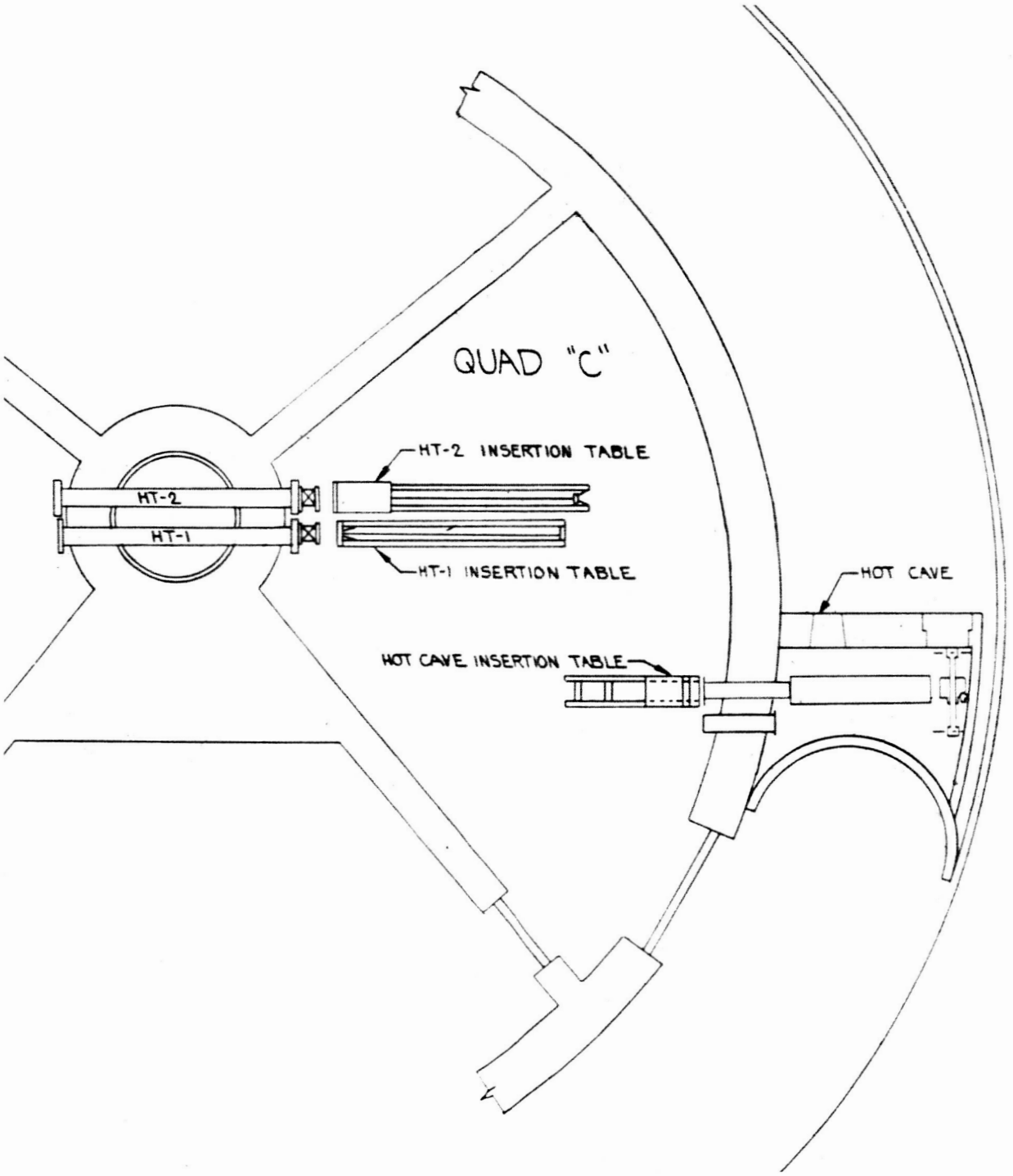


Image 99: Diagram of two insertion tables in Quadrant C. Experiments were loaded here and sent through the two horizontal through-holes or ports (HT-1 and HT-2) into the reactor core to be exposed to radiation. After irradiation, they were removed and maneuvered through the canals to the hot lab for analysis. (1965) (NASA PS65-1136)

Image 100: The technician on the walkway is operating the hydraulic cams, which insert and remove the experiment facility (seen in the bottom of the quadrant) into the core via Horizontal Through Hole 1 (HT-1). Experiment 62-12, a setup to evaluate the fuel and fission product retention qualities of tungsten-uranium dioxide dispersions (the dispersions were fission heated to anticipate the operating temperatures of rocket fuel elements), was permanently installed in Quadrant A. (NASA C–2003–827)

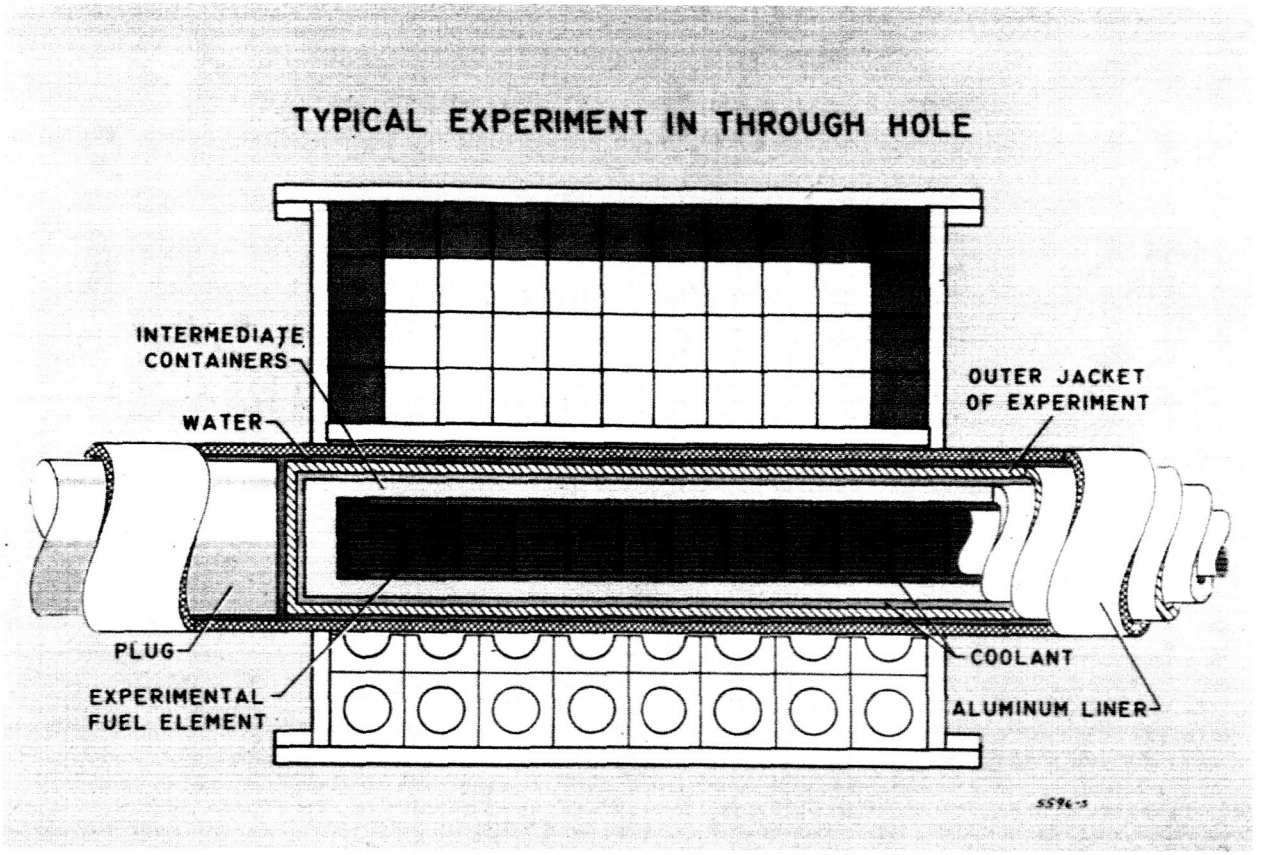


Image 101: Diagram of an experiment after it was inserted into HT-1. The fuel element is surrounded by coolant, water, several containment layers, and an outer jacket. A plug fills the test hole behind the experiment. HT-2 ran parallel to HT-1. (NASA CS-13591)

observations could be made. This experiment electrically energized the components during irradiation and special test circuits monitored their behavior and charted a graph comparing operation time versus radiation dosage received.[54]

To make the SNAP program more effective, scientists had to better understand the science of thermionics, or the conversion of heat into electricity. George Grover, from Los Alamos, initiated the first investigations that showed the possibility of thermionics. Plum Brook's first testing in this area was the Thermionic Diode Experiment (63-03), which attempted to demonstrate the feasibility of fission conversion. This conversion promised to be of great significance for space applications, because if it worked, the heat from the reactor could be used to power onboard electrical components. The experiment was placed in a vertical beam hole tube (VT-1). General Electric, through its Special Purpose Nuclear Systems Operation, sponsored a related experiment.[55] Funding for the project came from General Electric, along with support from NASA, the AEC, the Office of Nuclear Research (ONR), and the Advanced Research Projects Agency (ARPA). The experiment was a long-term test of cylindrical diodes to be used in nuclear thermionic power systems. The performance of the diodes was monitored during irradiation in the Plum Brook reactor, and then the diodes were examined at the Vallecitos Atomic Laboratory or in the Plum Brook hot laboratory.[56]

One of the most difficult problems that arose during the Plum Brook experimental program was quantifying how important its data was to the scientific community. These experiments were all considered basic research, meaning that the primary mission was simply to better understand how materials responded to a radioactive environment. It is often difficult to objectively measure

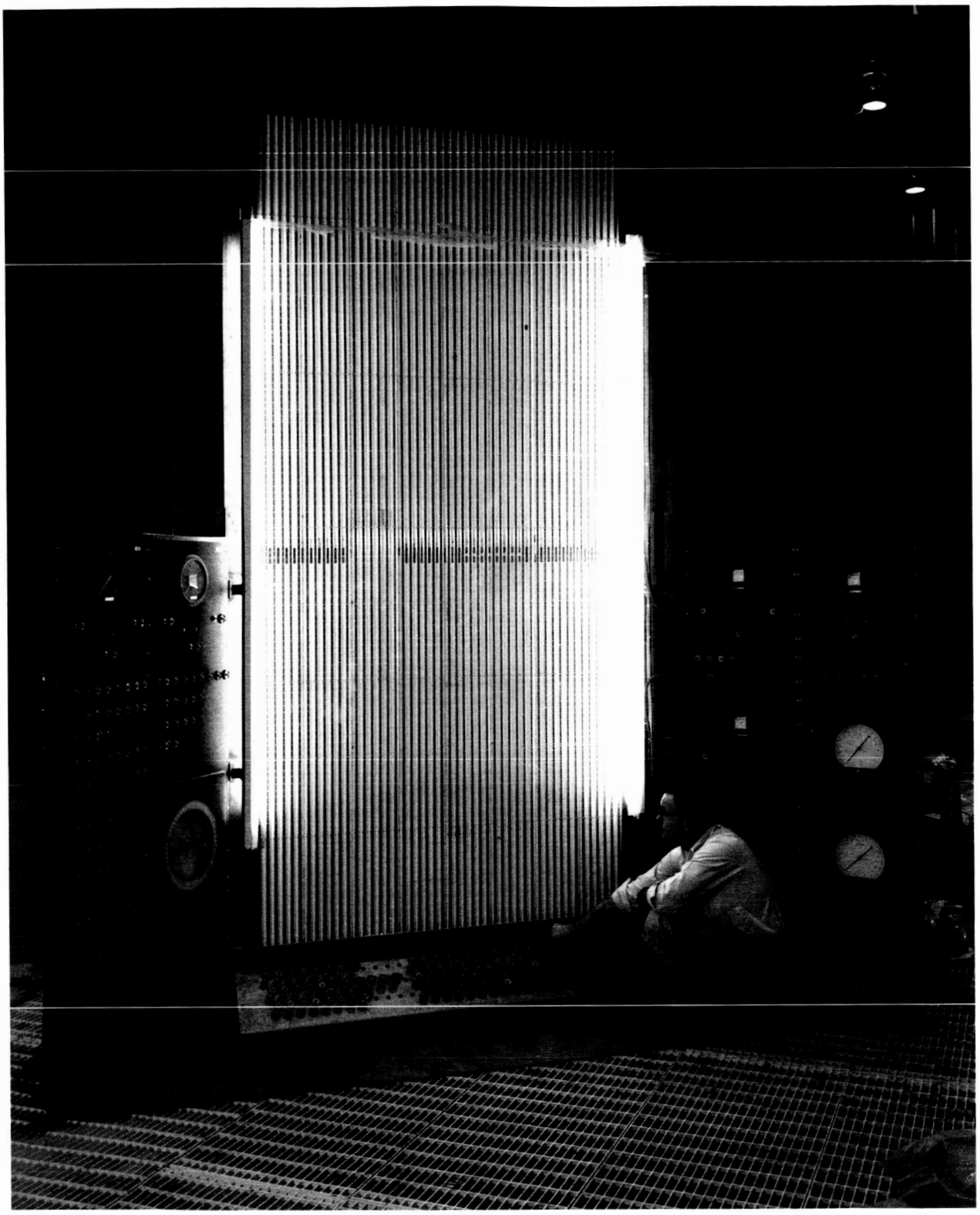


Image 102: John Hire adjusts an instrument console for final hydraulic testing prior to the reactor going critical for the first time. The console was on the lily pad area at the center of the quadrants, directly above the reactor pressure tank. (1960) (NASA C–1960–55125)

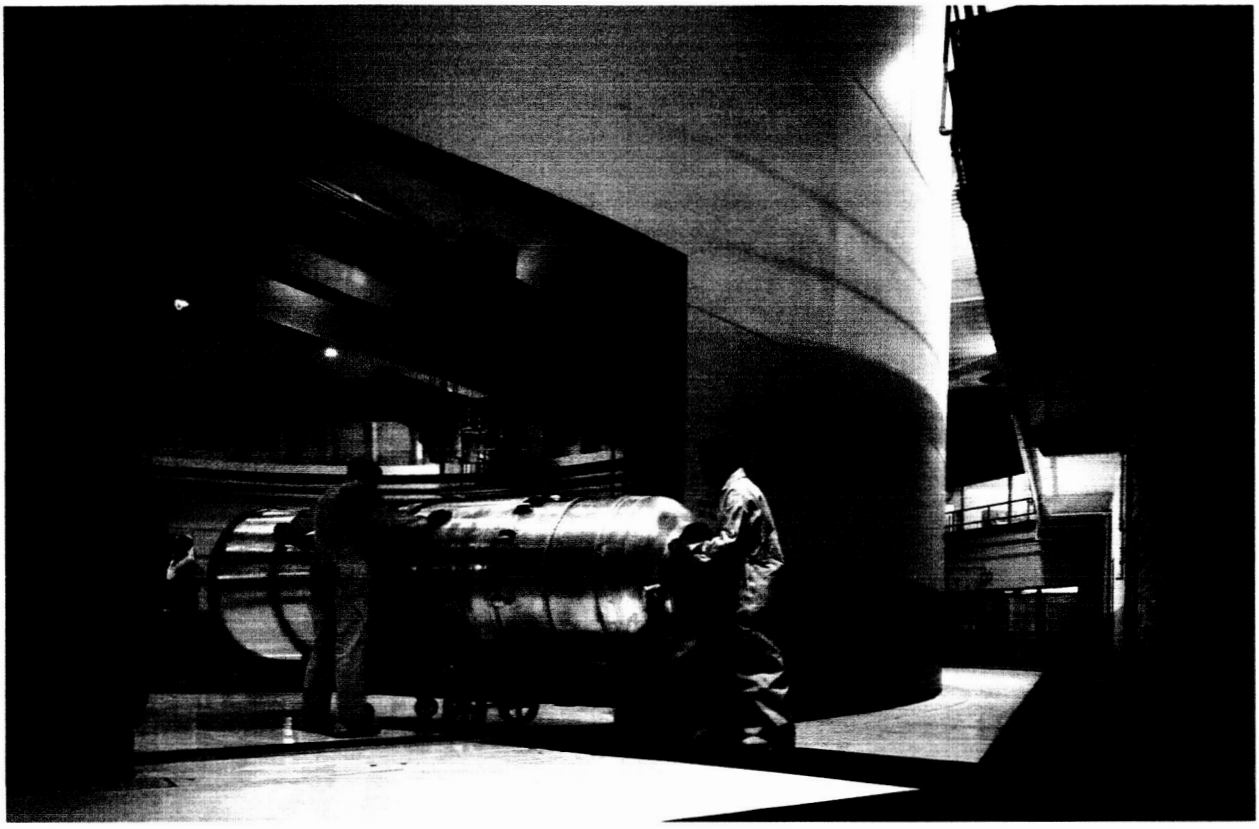


Image 103: Technicians wheel a large "thimble" containing experiments for irradiation into the containment vessel through the truck door. When the reactor was shut down and the protection of the containment barrier could be broken, this door was the only way large items of equipment and hardware could be taken in or out of the containment vessel, utilizing fork lifts if necessary. (1961) (NASA C-1961-55811)

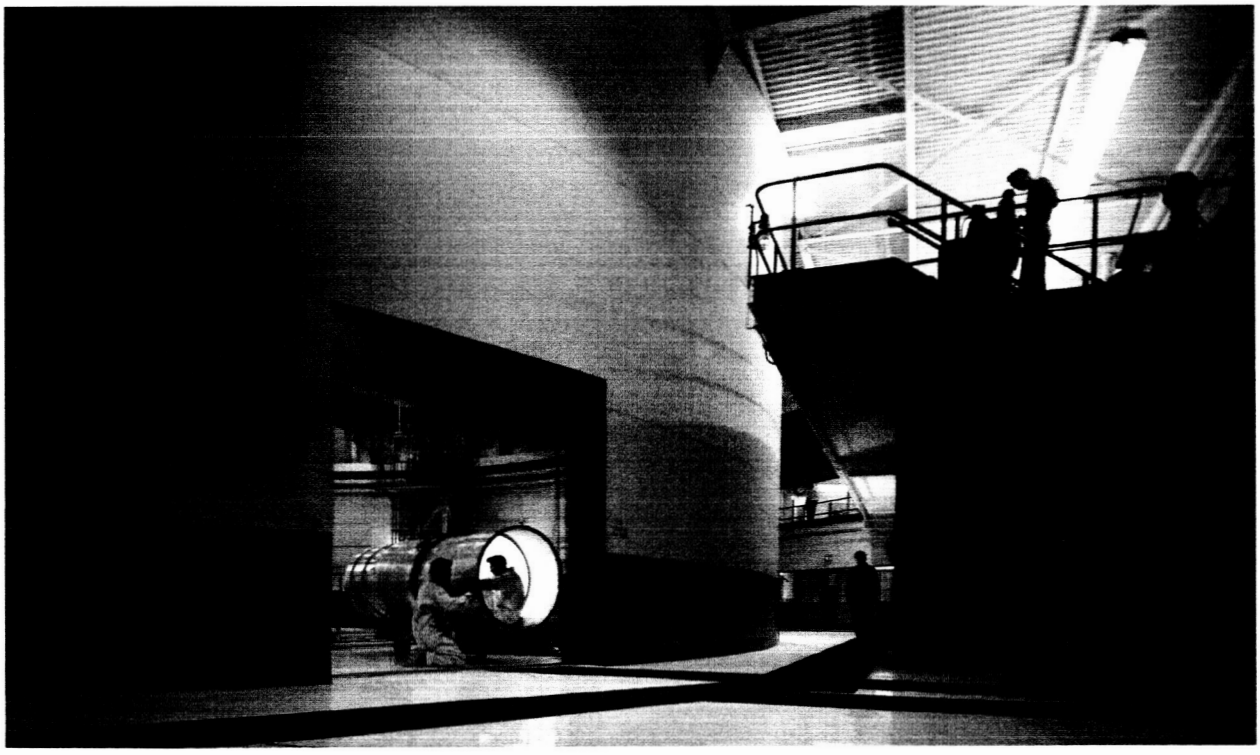


Image 104: Technicians work inside the thimble. (NASA C-1961-55810)

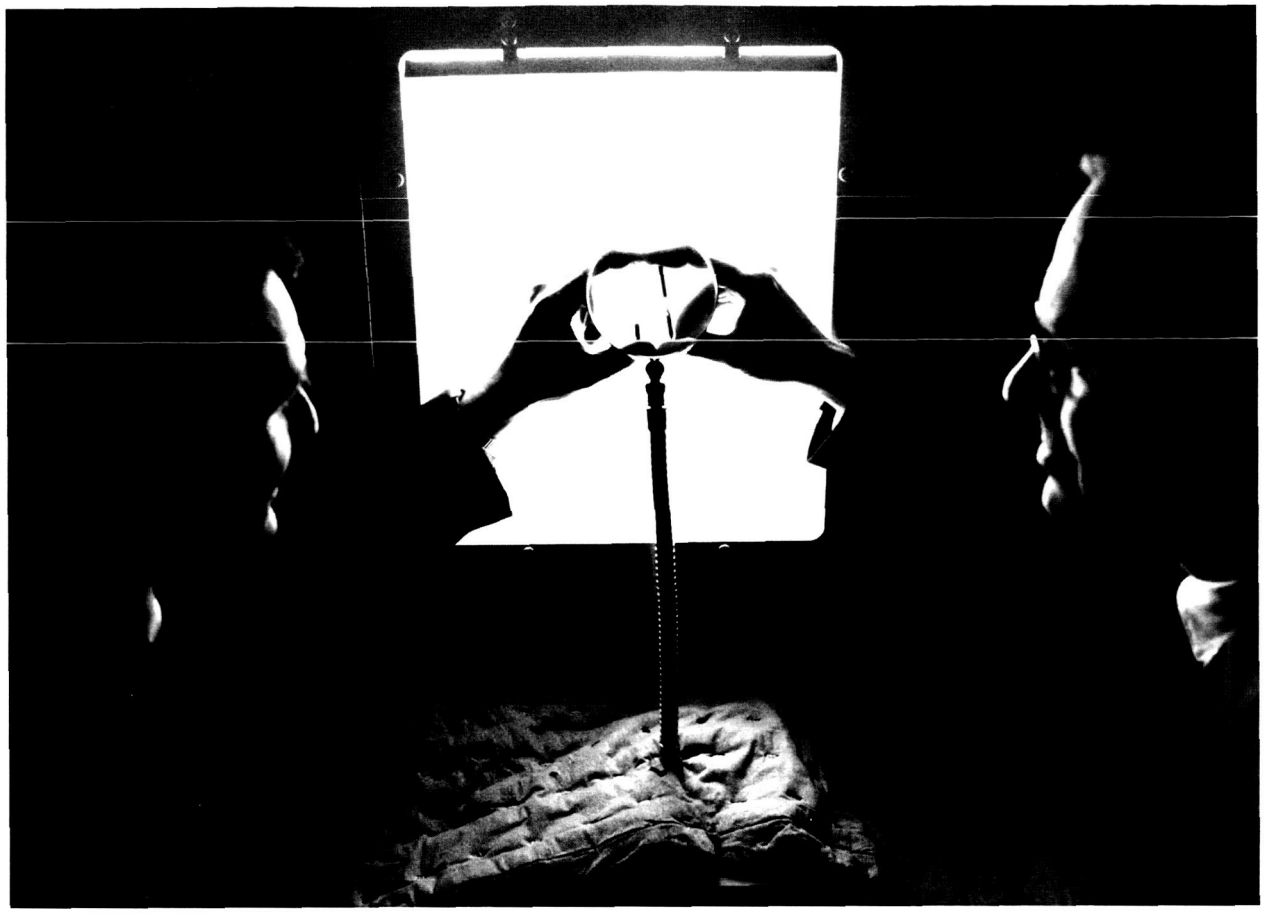


Image 105: Hap Johnson (left) and Brock Barkley (right) examine test specimens from an experimental run in the Plum Brook reactor. (NASA C-2004-741)

just how valuable and practical such research will turn out to be in the short term. However, the information gained from the Plum Brook reactor occasionally resulted in significant findings with immediate results. For example, during the Westinghouse NERVA Experiment in 1964, the reactor irradiated pressure transducers that were to be used for an upcoming full-scale reactor test in Nevada. During the early radiations the transducers failed, which was a complete surprise to the Westinghouse operators. This outcome forced them to develop new transducers for the test. Barkley said, "It's obvious how much more effective, economic, and important it was that the problems were detected in this reactor rather than waiting for the loss of the transducers to invalidate an extremely expensive and important full-scale NERVA reactor test."[57]

Nevertheless, a controversy over the importance of some of the reactor research developed. Not everyone believed that the data it was returning was valid. One engineer, speaking anonymously in a recent interview, said that he believed at the time that measurements taken from the cryogenic experiments had no statistical meaning. Even today, he questions the significance of the data. This engineer argued that while the cryogenic temperatures changed the physical properties of the materials, the radiation from the reactor itself had little, if any, measurable effect. He maintained that the same results would have been obtained if the materials were placed in cold storage alone, without any reactor present. Barkley was aware of this controversy and agreed that during the early years of the reactor, Plum Brook researchers were still struggling to determine how to best construct experiments to return significant

Image 106: Puncture rig. Puncture rigs were used to penetrate the outer capsule of each experiment and measure the pressure increase in the system due to released gases during irradiation. The plastic vial on the left was used to determine the isotope content of fission product gases, xenon and krypton, using gamma ray spectrometry; the tubular sample container below it was used to measure the volume percent of the two gases. The entire puncture operation and collection of gas samples was done inside the hot cells using the remote manipulators. The sample containers were then removed from the puncture rig and transferred to the radiochemistry laboratory for analysis. (NASA P69-3224)

data. By 1967, he felt confident enough to proclaim, "We now know how to obtain valid test data."[58] One year later, in a congratulatory report to his employees, Barkley said, "Plum Brook has the facilities and competence and is well on the road to becoming the standard for the industry in the field of radiation effects."[59]

In addition to the radiation damage studies on materials and nuclear fuels, the reactor rabbit facilities were used to support experimental programs for other government agencies using neutron activation analysis. These irradiations included jet fuel to determine trace element content in compliance with the Clean Air Act of 1970 (PL88-206). Corn and other grains were irradiated for the Department of Agriculture to determine trace element content, and analyses of fuels (such as crude oil, coal, and fly ash from coal-fired power plants) were performed on over 1,000 samples per year from 1971 to 1972 for the Environmental Protection Agency (EPA) (70-08). Dean W. Sheibley wrote, "This work is significant because it demonstrates that [instrumental neutron activation analysis] is a useful analytic tool for monitoring trace... elements related to environmental protection."[60] The research was also significant because it began proving that the work at the Plum Brook test reactor could extend beyond space applications.

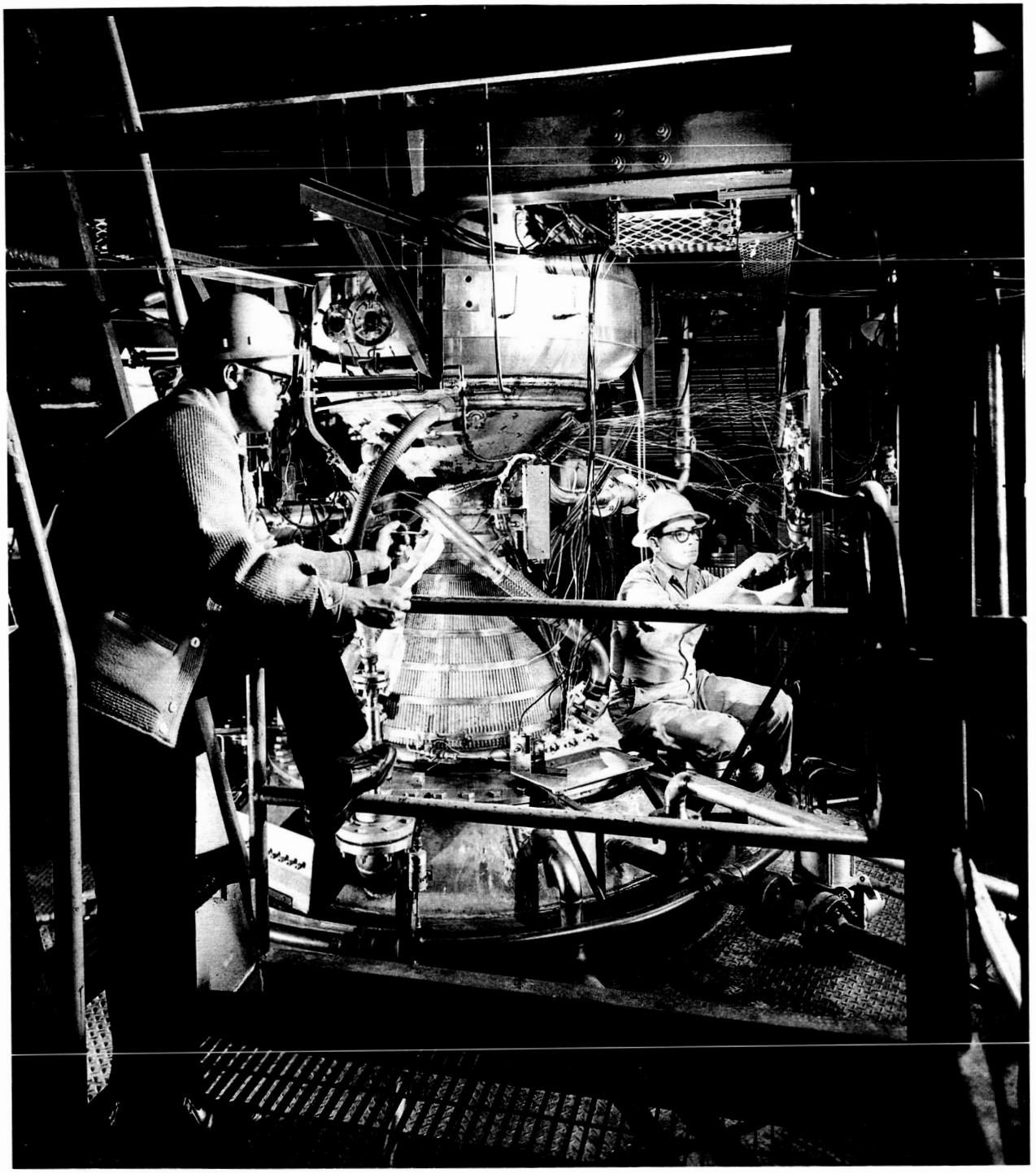


Image 107: NERVA engines are bolted to a vacuum test chamber in Plum Brook's B-2 facility. The test will help ensure that the engines will be able to start without an auxiliary power source. The B-2 facility was—and still is—the only place on Earth that can fire a full-scale engine and subject it to simulated harsh and demanding conditions of the space environment. The physical features of the B-2 facility are impressive. It has a huge stainless steel chamber thirty-eight feet in diameter and fifty-five feet tall. It can simulate the cold of space (–320 degrees Fahrenheit) with its liquid-nitrogen-cooled walls, and mimic the heat of the sun with its quartz lamp thermal simulators. Plum Brook engineers needed to maintain a vacuum, similar to space, in the B-2 chamber at the same time that the engines were firing and the test rocket was expelling hot gas. The answer was the development of speed ejectors, which were able to keep up with the exhaust output of the engines so that every cubic foot of gas was immediately removed from the chamber. Taken together, these features enabled engineers to simulate all the conditions of space, except zero gravity. (Cleveland Public Library Photograph Collection, Ohio, Sandusky, Industry, NASA, Plum Brook Station)

Plum Brook Station Test Facilities

Besides the reactor, other facilities at Plum Brook during the 1960s began making important contributions to the space program.

Image 108: The Hypersonic Tunnel Facility was capable of creating air velocities and temperatures that simulated flight speeds of seven times the speed of sound, at an altitude of 120,000 feet. (1969) (NASA C–1969–00725)

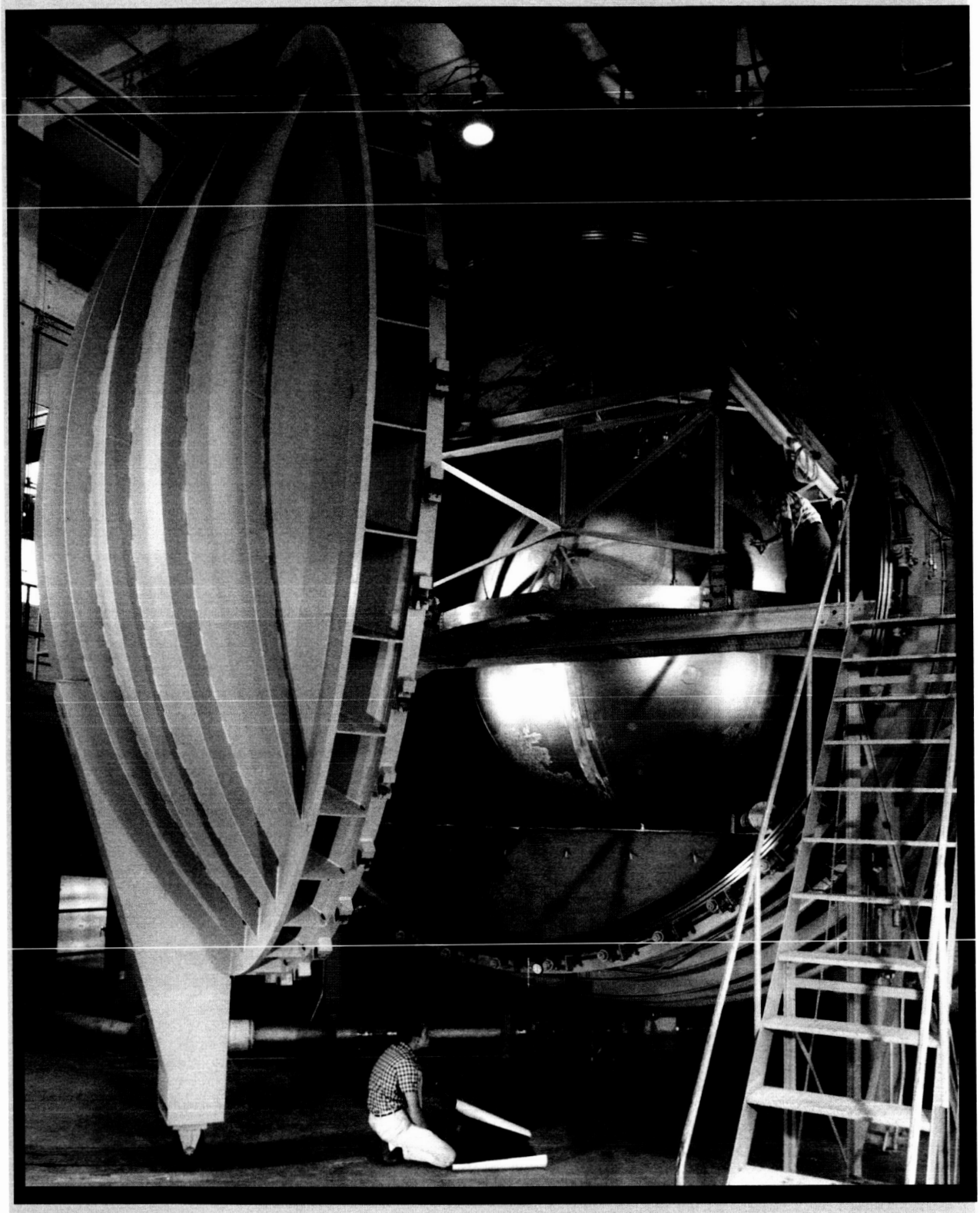


Image 109: The Cryogenic Propellant Tank Site (K-Site) was a test chamber for liquid hydrogen rocket fuel tanks. (1967) (NASA C–1967–03315)

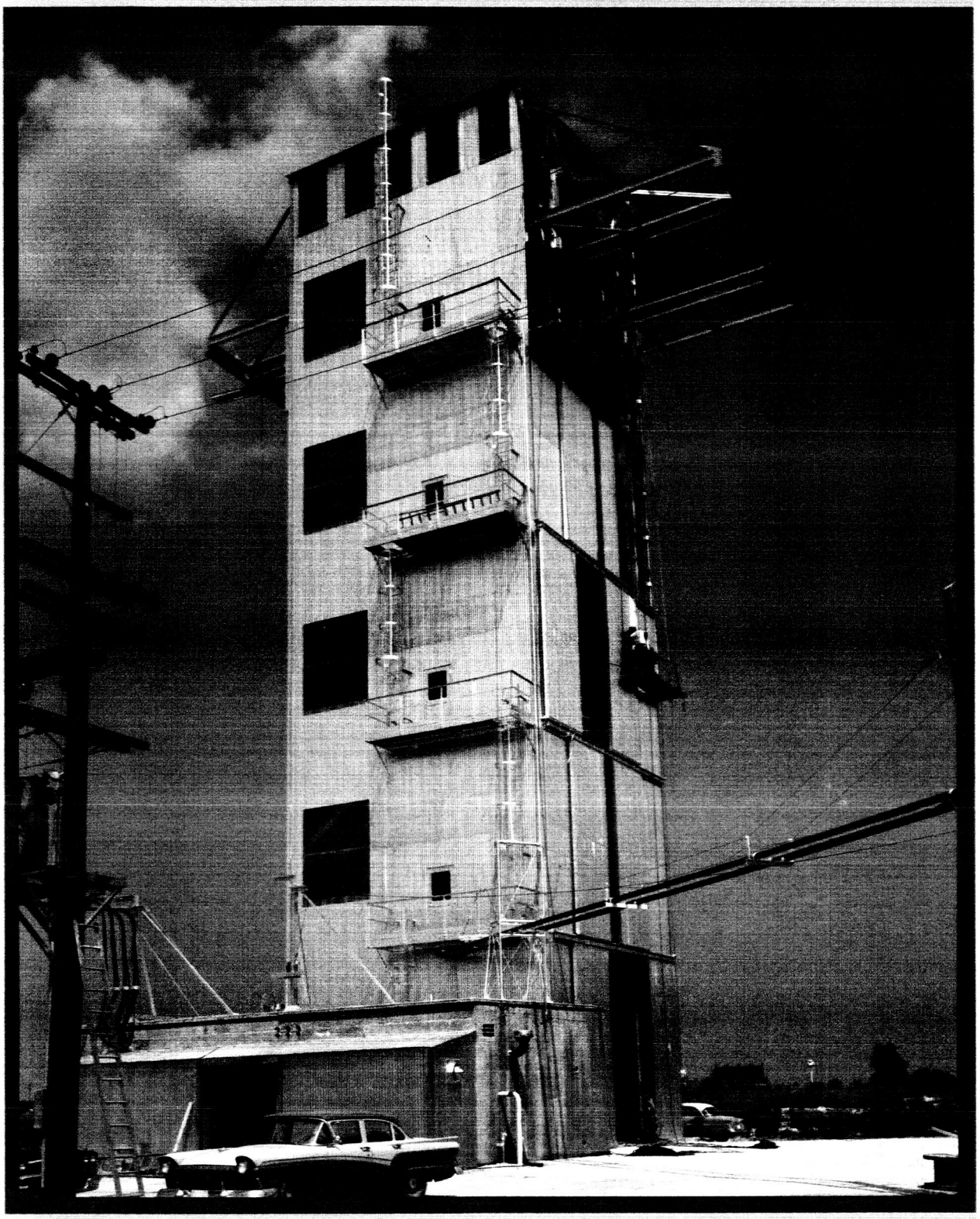


Image 110: Shake Tower. (1959) (NASA C–1959–51298)

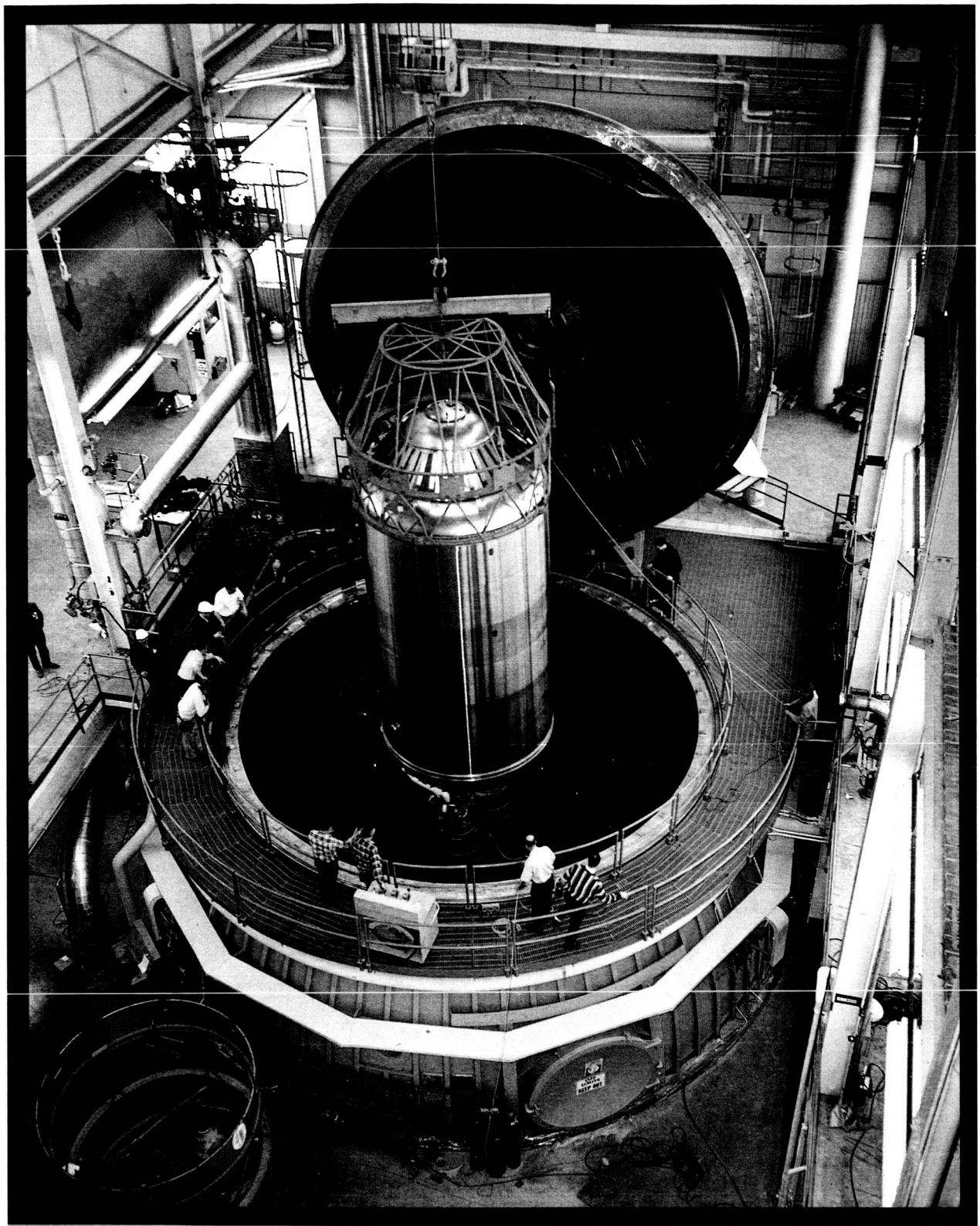


Image 111: The Spacecraft Propulsion Research Facility (B-2) was capable of testing space vehicles, and especially upper stage rockets like the Centaur, in a simulated space environment. The large vacuum test chamber could accommodate vehicles as large as 22 feet in diameter and 50 feet in length. The facility stood 74 feet high and extended 176 feet below ground. (NASA C–1999–00305)

Image 112: The Space Power Facility was the world's largest space environment simulation chamber when it was constructed in the 1960s, and it remains so today. It has a 100-foot diameter and stands 122 feet high. In this chamber, large space-bound hardware and spacecraft, even as large as the International Space Station, can be tested in an environment similar to that it will encounter in space. (1970) (NASA C–1970–03690)

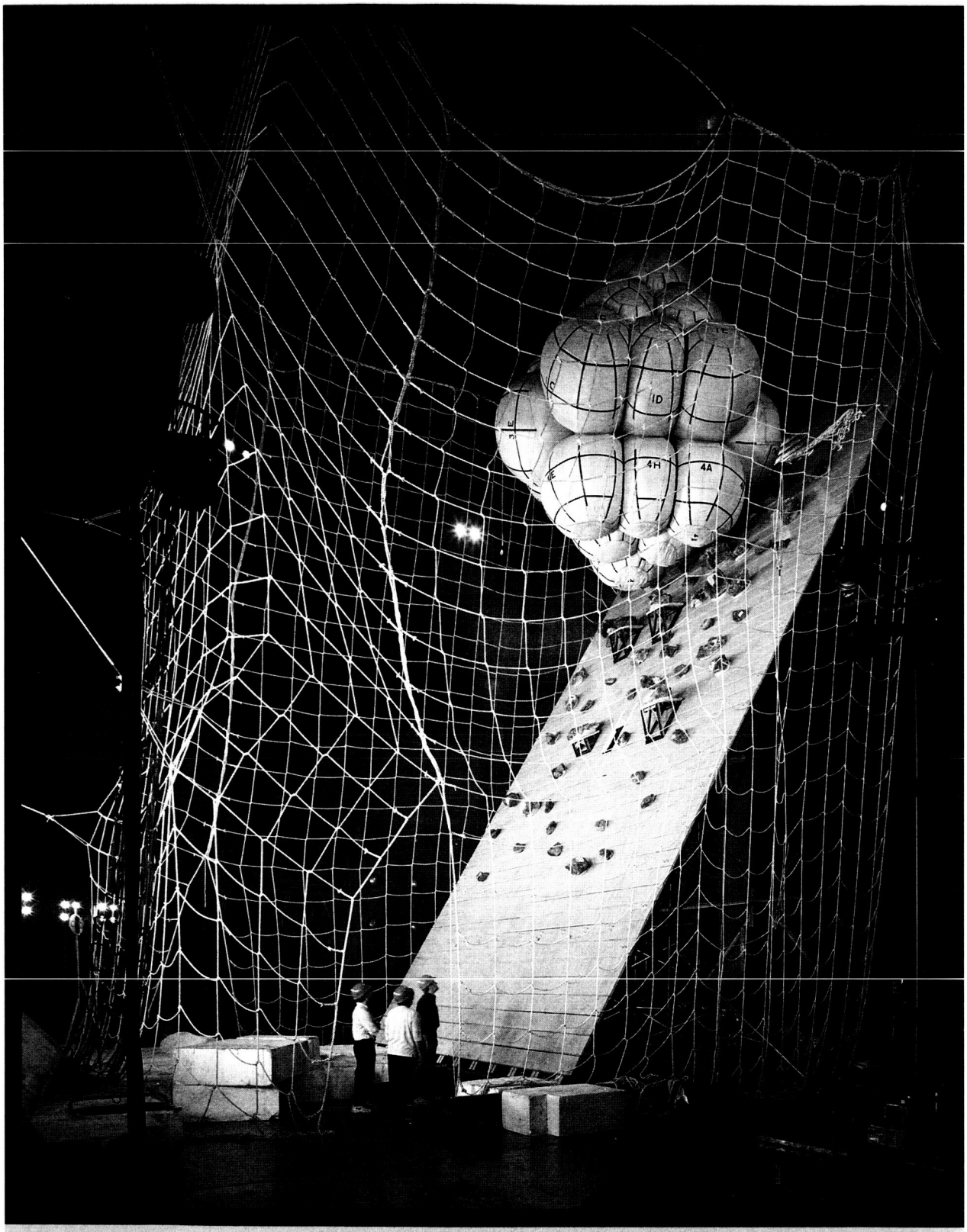


Image 113: In 1995, the airbags for Mars Pathfinder were tested in the Space Power Facility (SPF). (NASA C–1995–01861)

Plum Brook Station Social Activities

There was a great deal of camaraderie and socializing in the Plum Brook community. Employees and their families became close, since many were close in age and background and had all relocated together to the Sandusky area.

Image 114: Plum Brook employees enjoy an impromptu cookout. (NASA C-2003-844)

Images 115 and 116: Plum Brook events included formal dances and Christmas parties. (NASA C–2004–739)(NASA C–2003–845)

Image 117: Employees shared family gatherings like this April 1972 Easter egg hunt. (NASA C–2003–846)

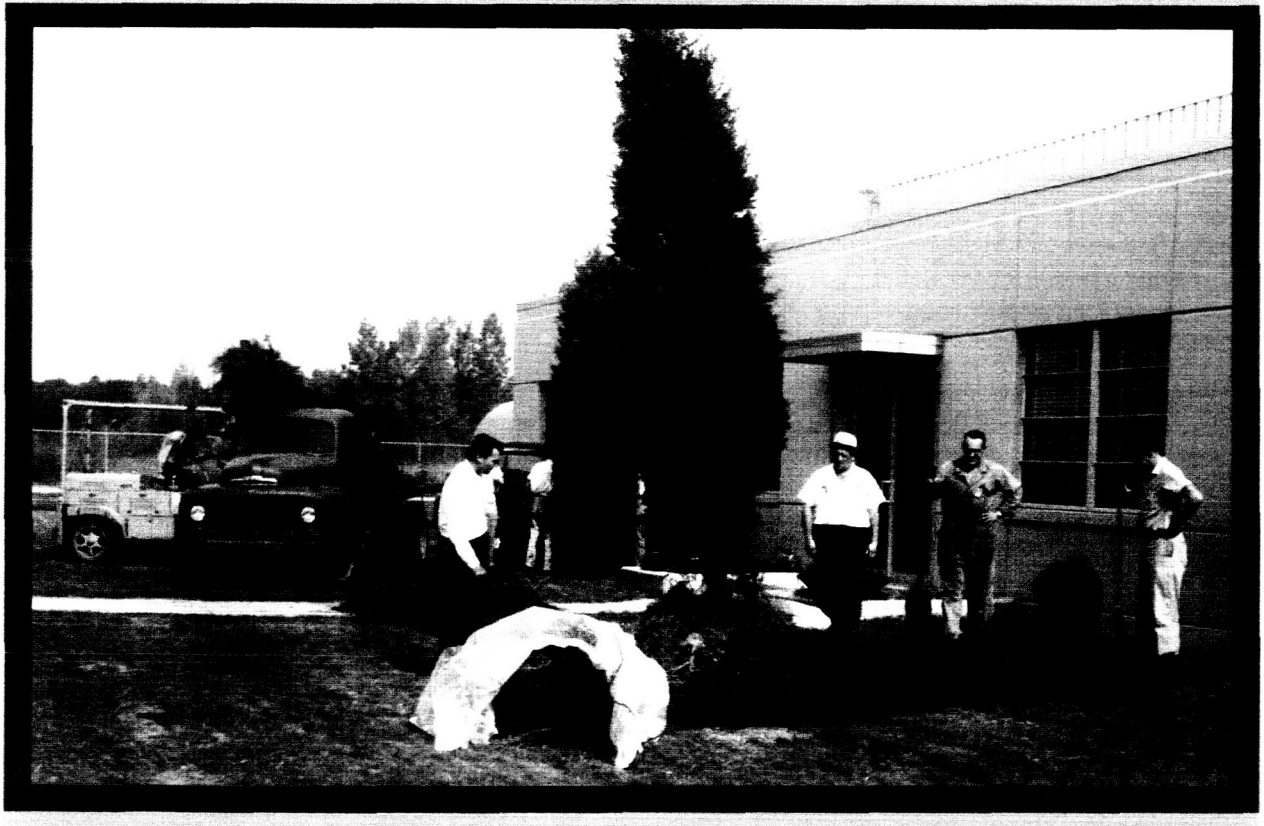


Image 118: Plum Brook Station Manager Hap Johnson endeavored to populate the Plum Brook landscape with trees. The land had largely been cleared during its use for Plum Brook Ordnance Works. Today the station has many wooded areas. (NASA C–2004–740)

Primary Document #8

In 1970, Robert Earl wrote a science fiction novel called Hot Lab, which was about the use of radioactivity as a scientific research tool. It took place at the fictitious Pine Valley Laboratories, where engineer Richard Rendfel, the book's protagonist, moved with his young family. The author was actually Robert Oldrieve, a hot lab manager at Plum Brook. It is uncanny that the fate that Oldrieve chose for his fictitious test reactor happened to the Plum Brook reactor just three years later.

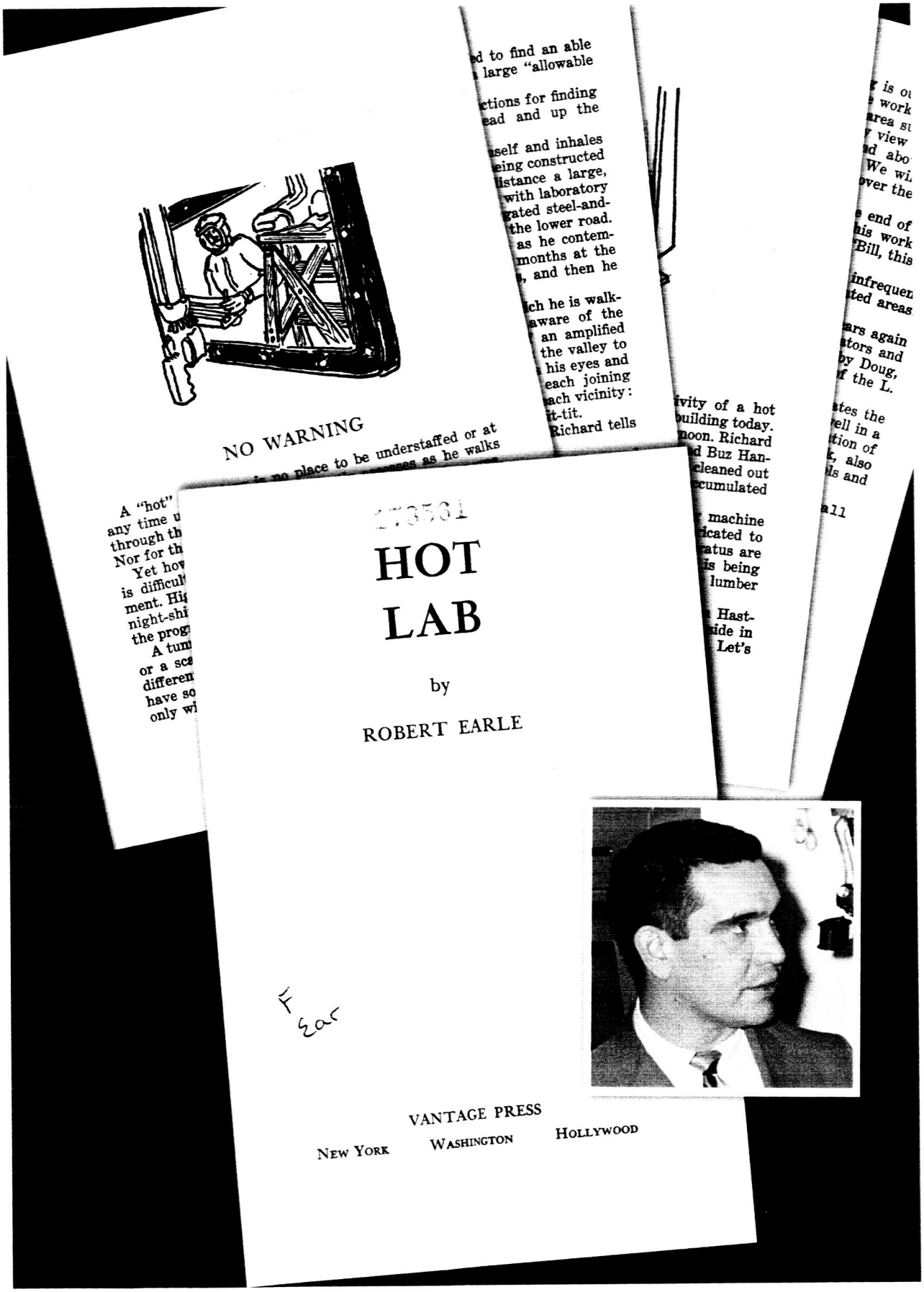
[Describing the hot laboratory]

We get nearly everything you can imagine: bottles of irradiated calf's liver, elastomers, transistors, timing devices, sledge hammer handles, and static eliminators for tape recorders. It seems that everybody wants to irradiate everything they can lay their hands on in hopes of a scientific or commercial breakthrough.

[Realizing that the entire reactor and hot laboratory might be closed]

The place could be shut down, without any great loss in relocation of the entire organization. The remoteness of the area isn't needed anymore. The capital assets aren't irreplaceable. Sure, most of the reactors are twenty years old or older, and the separation plant is no longer needed. I'll bet these technicians aren't paid enough; they came from the country areas, and most probably the plant is located here to take advantage of them! They had previously led simple lives, had few needs, and still require very little.

The final irony of the morning, aside from the fact that Pine Valley engineers could easily find jobs if relocation for them were necessary, is that...the entire Pine Valley Plant could be completely closed down without anyone being the wiser or really caring it if never reopened! Its almost tragic that no one really cares when someone else's job is abolished, not even if the job is an ultimately valuable and still current and required college-trained career.



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HOT LAB

by

ROBERT EARLE

VANTAGE PRESS

NEW YORK WASHINGTON HOLLYWOOD

Mothballing the Reactor

Despite the growing importance of the Plum Brook reactor's experimental program, it never became the leader in the field of radiation effects that its managers hoped it would. Budgetary cuts by the Nixon administration resulted in its closure before many of its experiments could be completed. The NASA scientists and engineers who suddenly lost their jobs were devastated. They first learned of the plans to shut the reactor down at noon, 5 January 1973, when Bruce Lundin, director of NASA's Lewis Research Center in nearby Cleveland, Ohio, assembled them in the Plum Brook auditorium to talk about the nation's post-Apollo vision for space. This vision included a new initiative called the Space Shuttle, but not a nuclear rocket. NASA's new goals were reusability, projects that promised short-term results, and quick and efficient access to space. The nuclear rocket had none of these attributes. Like the Apollo program, each nuclear rocket could be used only once, and its missions would consist of costly (and, some argued, environmentally dangerous) voyages into space. Though proponents of the nuclear rocket believed that they were ready to take on a Mars mission with astronauts, neither the budget nor the nuclear incentive remained.

Without a nuclear rocket there was no need for NASA's only large-scale nuclear test reactor. The closure was to be immediate, meaning that very day. The reactor employees were unprepared for this decision. The reactor had just received a new load of fuel elements and was ready to run another several years. In addition, many of the experiments had just commenced when the shutdown announcement came. The stunned and dejected Plum Brook employees returned to their reactor in a somber mood. Hours later the entire shift stood in the control room and watched Don Rhodes and Bill Fecych shut the reactor down for the last time. Plum Brook engineer Earl Boitel recalled, "That was a very traumatic experience. There were a lot of tears in people's eyes."[62] As they began looking for other jobs, Plum Brook personnel lamented that one of

Image 119: The Apollo 17 crew—Eugene Cernan, Ronald Evans, and Harrison Schmidt—visit Lewis Research Center and have their picture taken with Bruce Lundin. The Apollo 17 astronauts were the last humans to walk on the Moon on 14 December 1972. Just over two weeks later, NASA Lewis Research Center Director Bruce Lundin ordered the closure of the Plum Brook nuclear reactor due to budgetary cuts for long-term space projects. This photograph was taken about five weeks after the Plum Brook reactor shutdown. (16 February 1973) (NASA C-1973-00774)

the most powerful test reactors in the world was not even given the opportunity to complete its last experimental cycle. In an effort to vent their frustration, reactor engineers filled chalkboards once reserved for nuclear research with cartoons of Plum Brook as a sinking ship.

Plum Brook was not alone, as many reactor facilities were forced to close nationwide. The Brookhaven Graphite Research Reactor closed in 1969, the Materials Test Reactor closed in 1970, and a Los Alamos reactor shut down in 1974. The AEC's influence was also in decline. After a 1971 Supreme Court ruling on AEC licensing procedures, the commission was forced to streamline its organization and procedures. Critics claimed that it was improper for the agency to regulate the very same reactors that it managed. The AEC, which was founded in August 1946, officially suspended operations in October 1974 when President Ford signed the Energy Reorganization Act. The Act placed the AEC's research and development functions under the Energy Research Development Administration and its licensing functions under the Nuclear Regulatory Commission.

The shutdown of the reactor did not mean that the work was complete. The reactor team was given six months to place the facility in standby mode. By 30 June 1973, this carefully executed

Primary Document #9

The first time the Plum Brook reactor employees knew that their reactor would be shut down was during the following speech made by Bruce Lundin, the center director at NASA Lewis Research Center. The speech was made at noon on 5 January 1973 at the Plum Brook auditorium. Just a few hours later the reactor was shut down for the last time. The following is an edited and excerpted transcript from an audiotape recording of the event.

PLUM BROOK SHUT DOWN SPEECH
Bruce Lundin

Members of the staff of Plum Brook Station, I've asked that we meet together here at this time to enable me to tell you all that I know and all that I can about what I learned yesterday when I was with Jim Fletcher [NASA Administrator] and George Low [NASA Deputy Administrator] and others in Washington. Our country's current fiscal management and fiscal problems and some of the program actions at NASA will have a very significant effect on all of us. I was anxious to do this at the very earliest possible moment. I'd just like to check this point, I'm required to check that only NASA Lewis civil service personnel are present here in this room. You'll see at the end a little timetable for spreading this information to broader circles than just the Lewis people.

First I'd like to give you just a few words about the total national picture to provide background for you and to put our necessary Lewis actions into some total picture, total context. I'll do this in a sketchy brief way so I can get to matters more important to all of us as quickly as possible.

Jim Fletcher has been working very closely with President Nixon the last few days, and of course with Nixon's staff, the Office of Management and Budget, the staff arm of the president. And from Jim Fletcher's very open and candid remarks to all of us yesterday it became terribly clear. This will be no real surprise from what you've been reading in the newspaper. The President is completely determined to limit federal outlays and expenditures this year to that 250 billion dollar number, to have no new taxes on the people, and to reduce the size of what Nixon refers to as a federal bureaucracy. If after doing all of these things he can have a strong defense establishment, he'd like that too. But the President, and from the actions that Jim Fletcher had observed in Washington, the President is indeed clear that he's going to restrict federal expenditures and have no new taxes.

We don't know the specifics to the different agencies because of the way the President's been running this problem. But Jim Fletcher has touched base with his colleagues in Washington and other agencies, and he got the very clear picture of large wholesale cuts everywhere. And this will be unfolding, of course, during the month and made clear in the President's budget message on or around January 29th. Some entire agencies are disappearing completely. Many of the so-called soft programs or Great Society programs will be gone. And that was the general picture of Nixon's management of the fiscal matters in the country.

As regards NASA now, Jim Fletcher had an understanding and gentleman's agreement with the President that NASA could count on running on what was called his level budget concept, which was somewhat over 3 billion dollars a year. That level budget understanding is now gone. And Fletcher spoke of considerable disappointment that he

had to give up his level budget concept. As regards NASA for the rest of this fiscal year and the impact into fiscal '74, we find that the Shuttle is in and the Apollo-Soyuz link up to the docking with the Russians in space in '75 is in. Those two items are in by Presidential direction. The Viking Program is in the budget. Our launch vehicle activities are secure. Skylab is, of course, going to fly in April so that will be done. Many other programs are disappearing from NASA.

Now as regards Lewis Research Center, NASA finds it has to fit its total program under some, not only reductions in the New Obligation Authority in fiscal '74, but more importantly, even to fit under a very tight cost limit this current fiscal year. To fit under that, NASA management and the Office of Management and Budget, have found it necessary to decide to terminate all research work that cannot be expected to have a needed or useful application, say for a period of, within this decade. Long-range research and development work that cannot be expected to have a real need or application until the 1980s must be terminated at this time and priority given to more shorter range activities in say the 3 to 5 year time span. This means that essentially all nuclear power and nuclear propulsion R&D work will be terminated this fiscal year.

In view of the total national picture, and after seeing this, working with the folks in Washington, I can understand this and can therefore accept the rational for this decision. It's one I don't agree with, I don't think that it's exactly right to do it just this way, but I can understand it and accept it and that's what all of us have to do now. This means, of course, that the reactor here at Plum Brook will be closed down during the remainder of this current fiscal year. Further, the rest of Plum Brook Station will have to be closed down at the end of fiscal 1974. This, I should emphasize, will be done in a manner in which we leave it in a, what we call a standby or mothball condition. It's not to be abandoned in place and surplused off because all of us in NASA management are confident that many of these very unique and important facilities and people will be coming back to them to do work in them, when the space program reaches the point when they are needed. This will be, of course, a massive and challenging, difficult job. It's about the toughest job in management.

As far as the people go, there will be reductions in force both this fiscal year between now and June 30th and into next fiscal year. For Lewis I can't give you exact numbers because they're not worked out in that kind of detail yet. For Lewis it will mean a reduction in force of around 400 by June 30th, generally 50/50 between here and Cleveland. And another 2 to 300 people by the end of fiscal '74.

You will hear in the days and weeks ahead, quite a bit of talk, you'll be engaged in some of this conversation yourself, you'll certainly read it in the newspapers or hear it on the radio, about a lot of flack going on in Congress. The Congress and the President are in many ways running on a collision course. It's going to be a very active time between the White House and the Hill this spring.

My response to all of this? What happened to me a week or few days ago is the same thing that's happening to you now. You suffer a shock that you can't quite believe it, a feeling of pain and anguish, of course, and you lick your wounds for a day or two. Then you decide that's not very constructive so where do we go from here? We are completely dedicated to at least two things at this point. One is to do a very first-class orderly job of finishing our work here. And secondly we're going to be completely dedicated to finding every one of you that wants a job, a good job someplace. I intend to, Monday, as soon as I can, to call such people as Tom Paine and Harry Finger and

many of my other friends in other agencies in government now that I can tell them what's happening and make your interests and capabilities known to them. We're going to set up here and in Cleveland a real massive outplacement service for you. The fact that you possess unusual skills and capabilities and experience, I've discovered, is known everywhere throughout the country and Washington and there will be interest in a lot of places of making use of your skills and experience if the people have the ability to expand their staffs.

My own sort of philosophical views here now . . . As I think back on all of this I think nuclear reactor power for space really disappeared about four years ago when Tom Paine opted for the shuttle instead of the space station when he was told he could only have one of the two. Plum Brook was really created for a space program that simply didn't materialize at a rate that permits it to be sustained now. The space program simply has slipped downstream in point of time.

I was anxious to tell you the same time that the Congressman Mosher was hearing it. I will be leaving here in a few minutes and going back and telling the folks in Cleveland about this, so you're the first to hear. Contractor management will be informed at 1:00 today but that will be for management information. There will be a press release coming out of Washington and out of here and Cleveland at 4:00 this afternoon. All of this information is restricted to government employees, except for notifying contractor management. At 4:00 a document becomes public in Washington. No doubt when many of you get back to your desk, your phones will start to ring and people will be asking you what was the meeting here for and what's going to happen and so forth. I'll have to ask you to tell them, "We always have meetings but it was nothing of particular concern at this time."

[murmuring from the crowd]

That's about all I can say. That's all I know. I've told you everything that I know up to this time. Probably a little bit more than I should have about some things. I don't feel that there are any more questions that I could answer at this time. So thanks for your attention and coming here and I'll be seeing all of you, I know, again in the days and weeks ahead.

Thank you.

Hobbies, travel beckon retirees...

Richard D. Faldetta, joined Lewis
in 1944 after a 1 1/2 year stin
the U.S. Army. He has been H
the Electrical Design Section A
trical Design Branch, Faciliti
gineering Division for the past 1
During his career here he has
volved in research and facility
He and his wife, Mary, have four grown children
joys tennis, golf and swimming.

Minerva Simon joined Lewis in
1963. Prior to that she was with the
Finance Center for 20 years and

Clyde J. Greer will be we
time as a project director at
land Regional Water Pollutio
ity. He completes 20 years
service this month. Before jo
Brook in March 1959 he w
Erie Ordnance Depot and
Air Force. For the past t
Plum Brook he has been Head, Reactor Electi
periment Service Section, Reactor Service Brar
Service Division. He and his wife, Doris, have
and two grandsons. He enjoys boating, fishing
on automobiles.

James P. Lewis winds
years of government
month. After a two yea
U.S. Army he joined
He is an aerospace e
STOL Project Propuls
STOL and Noise Divisi

Plum Brook to close

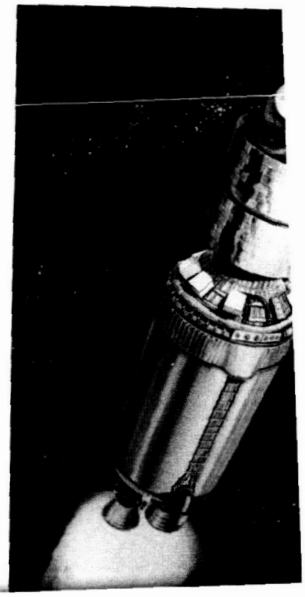
Nuclear propulsion, power projects to phase out

Director Bruce T. Lundin, announced to employees of the Center on January 5 that the necessity to reduce Federal expenditures during the current fiscal year and beyond has forced a significant reduction in many of NASA's current and planned programs. These reductions affect the expenditure level for the remainder of this fiscal year and planning for fiscal year 1974. In general long range research and technology efforts not expected to be needed for some time in the future will be reduced or terminated. Priority will be given to more urgently needed (near-term) work.

The impact on Lewis will be the termination of essentially all of the current nuclear propulsion and power programs by the end of this fiscal year. Major facilities not to be utilized in NASA's restructured program will be phased out and placed in standby condition. At the Plum Brook Station, the Reactor Facility will be placed in standby condition by the end of this fiscal year and the remainder of the Station will be closed by the end of Fiscal Year 1974.

The closedown of Plum Brook and program terminations at the Lewis Cleveland site will result in the separation of many employees over the next 18 months.

Officials expect a reduction of about 600 Civil Service positions at Cleveland and Plum Brook. About half of these jobs will be eliminated by the end of this fiscal year, the others during FY 1974. This reduction is in addition to the earlier planned reduction of 90 that must be made by the end of FY 1973.



NASA explains cutbacks

NASA has made a number of program reductions to adjust its activities in aircraft.

The actions announced cations satellites. In research and technology, work on

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He and his wife,
grandson.

Lab mounts massive placement drive

Almost as soon as official notice came of Plum Brook's closing and manpower cutbacks at Lewis-Cleveland, a massive drive got underway "to find a position for everyone affected by the RIF who needs help," says Dr. Bernard Lubarsky, Deputy Director, Technology.

At the direction of top management, an Employment Committee was formed ing Design Division, several Plum Brook divisions and several divisions under the technical services directorate.

"One of the most important factors in the placement efforts has been the strong support of top management. Center Director Bruce T. Lundin has spent long hours contacting companies and arranging for future con- between our Personnel

The first step of the Employment Committee was opening the Outplacement Service Office in the basement of the DEB-Annex. "The office is set up to give all the help we can to the affected employees, but it is not intended to replace their own efforts," he explained.

The Outplacement Service Office activities are broken down into the fol-

Through Director Lundin's efforts

Leading figures seek uses for PB

Lewis is taking action to interest other organizations in the capabilities of its 8000-acre Plum Brook Station.

A major symposium has been organized for leading executives in government, education, business and industry to explore ways in which the nation can best use the facility and personnel. The symposium hosted by Lewis Director Bruce T. Lundin will be held April 23 and 24 at the Plum Brook Station.

It was announced by NASA Headquarters in January that, in order to meet Federal budget targets, the agency had to cut back in several areas of work, personnel and facilities. Plum Brook facilities include a 60-megawatt nuclear research reactor which is one of the most versatile in the nation, and the world's largest environmental simulator which can duplicate and maintain air densities from sea level to the vacuum of space at temperatures rang-

ing from minus 300 degrees Fahrenheit to plus 180 degrees F.

Since the announced closure Director Bruce T. Lundin and other interested Center personnel have been exploring other possible uses for the unique Plum Brook facilities. A strong effort at finding new jobs for the more than 700 highly trained scientists, engineers and

Science Foundation, Major foundations, universities and Ohio State government departments are also represented.

A brochure outlining the capabilities of various facilities at Plum Brook has been prepared and sent to invitees. In his introduction to the brochure Lundin emphasizes creative thinking about the station with some suggestions of his own. He points out that in addition to the specific facilities, the large open land areas at Plum Brook, which originally were needed for hazard-exclusion distances, "now offer attractive potential for other purposes such as noise abatement research, road and railroad test tracks, or perhaps...ground-effects machine development.

ranges interviews, assists employees in establishing contacts with prospective employees, and sends resumes. Sam Barile is heading this function. He is assisted by Robert G. Ragsdale. Ragsdale can be reached at PAX 8431 or PBX 6409 and 8431 or PBX 409 and Barile at PAX 8240 and PBX 373.

The final activity under the Outplacement Office is the statistics and operations

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Robert J. Usher of
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dinating efforts with
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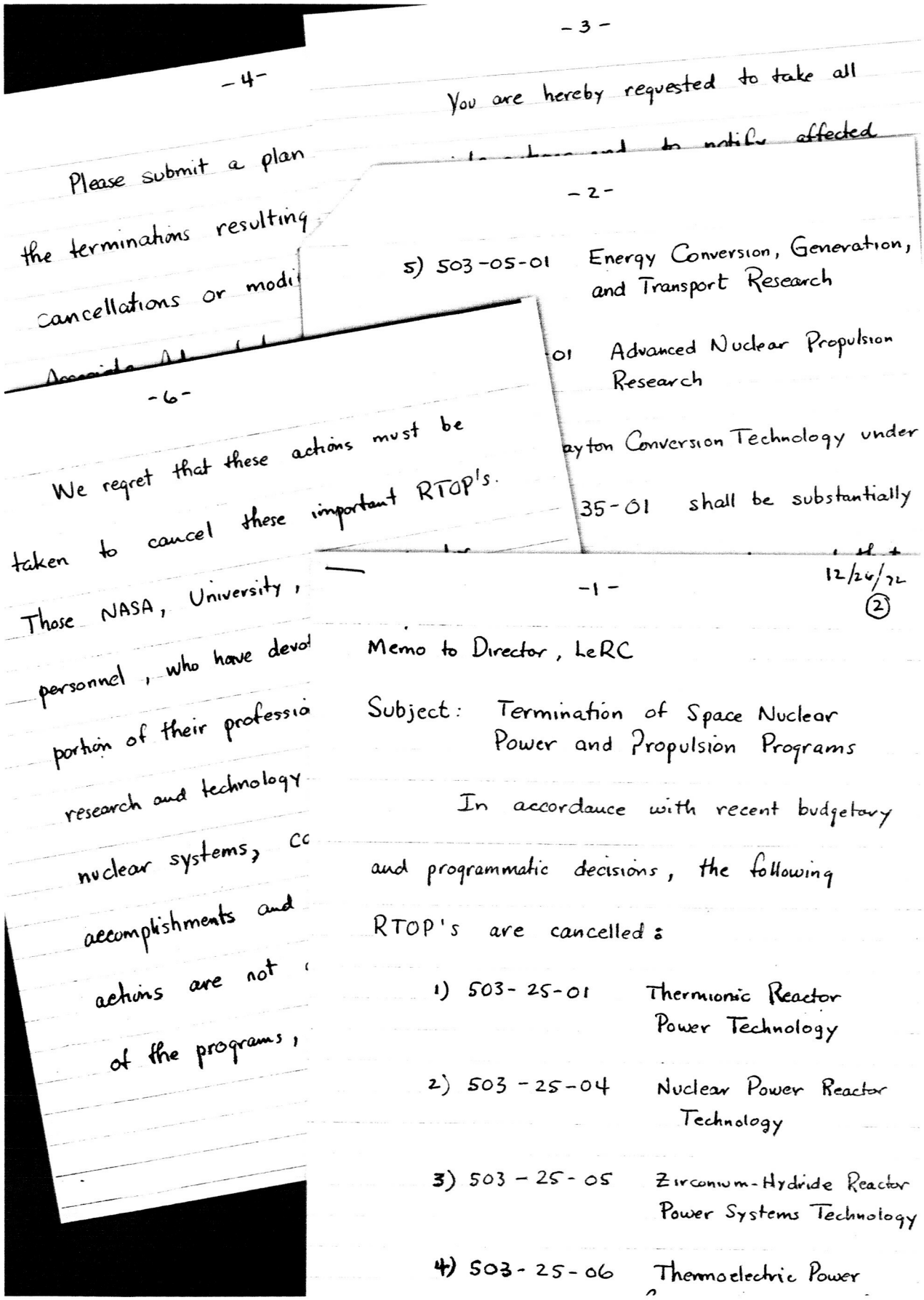
nautics and Astronau
(AIAA). AIAA has condu



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5) 503-05-01 Energy Conversion, Generation, and Transport Research

01 Advanced Nuclear Propulsion Research

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35-01 shall be substantially

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We regret that these actions must be

taken to cancel these important RTOP's.

Those NASA, University,

personnel, who have devo

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12/26/72

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Memo to Director, LeRC

Subject: Termination of Space Nuclear Power and Propulsion Programs

In accordance with recent budgetary and programmatic decisions, the following RTOP's are cancelled:

1) 503-25-01 Thermionic Reactor Power Technology

2) 503-25-04 Nuclear Power Reactor Technology

3) 503-25-05 Zirconium-Hydride Reactor Power Systems Technology

4) 503-25-06 Thermoelectric Power

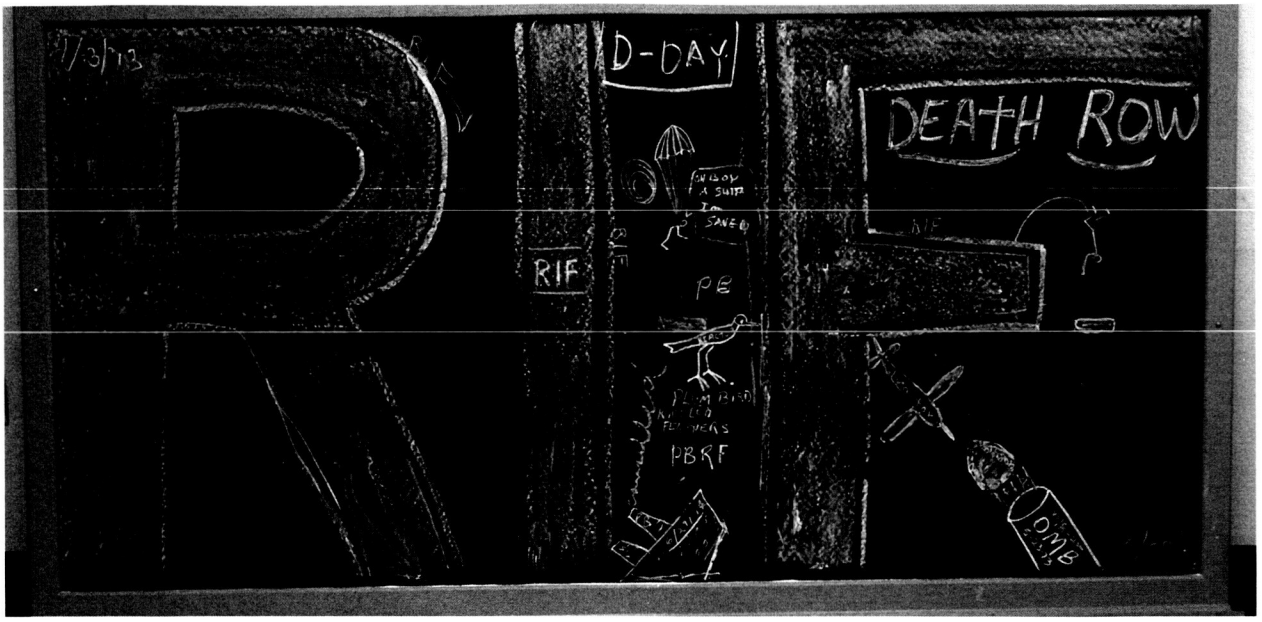


Image 120: This blackboard graffiti expresses the sentiments of Plum Brook employees after learning about the reactor shutdown. It went untouched for over twenty-five years and is now being preserved as a museum artifact. RIF stands for "reduction in force," which is the standard expression for layoffs at federal facilities. The graffiti was one way in which employees expressed their deep feelings of frustration. Other graffiti includes, "Old reactors never die, they just decay away," and "Decay in peace." (2001) (NASA C-2001-01166)

Image 121: Bill Fecych shut down the reactor for the last time on 5 January 1973, as Dale McCutheon, Dan Gardner, George Gowan, and others looked on. Employees had gathered in the Plum Brook auditorium for an announcement by Lewis Center Director Bruce Lundin, little expecting to hear the news that Plum Brook would be closed. Two hours later, stunned employees crowded into the reactor control room and, just after 2 p.m., witnessed the final shutdown of the Plum Brook reactor. (NASA C-2003-847)

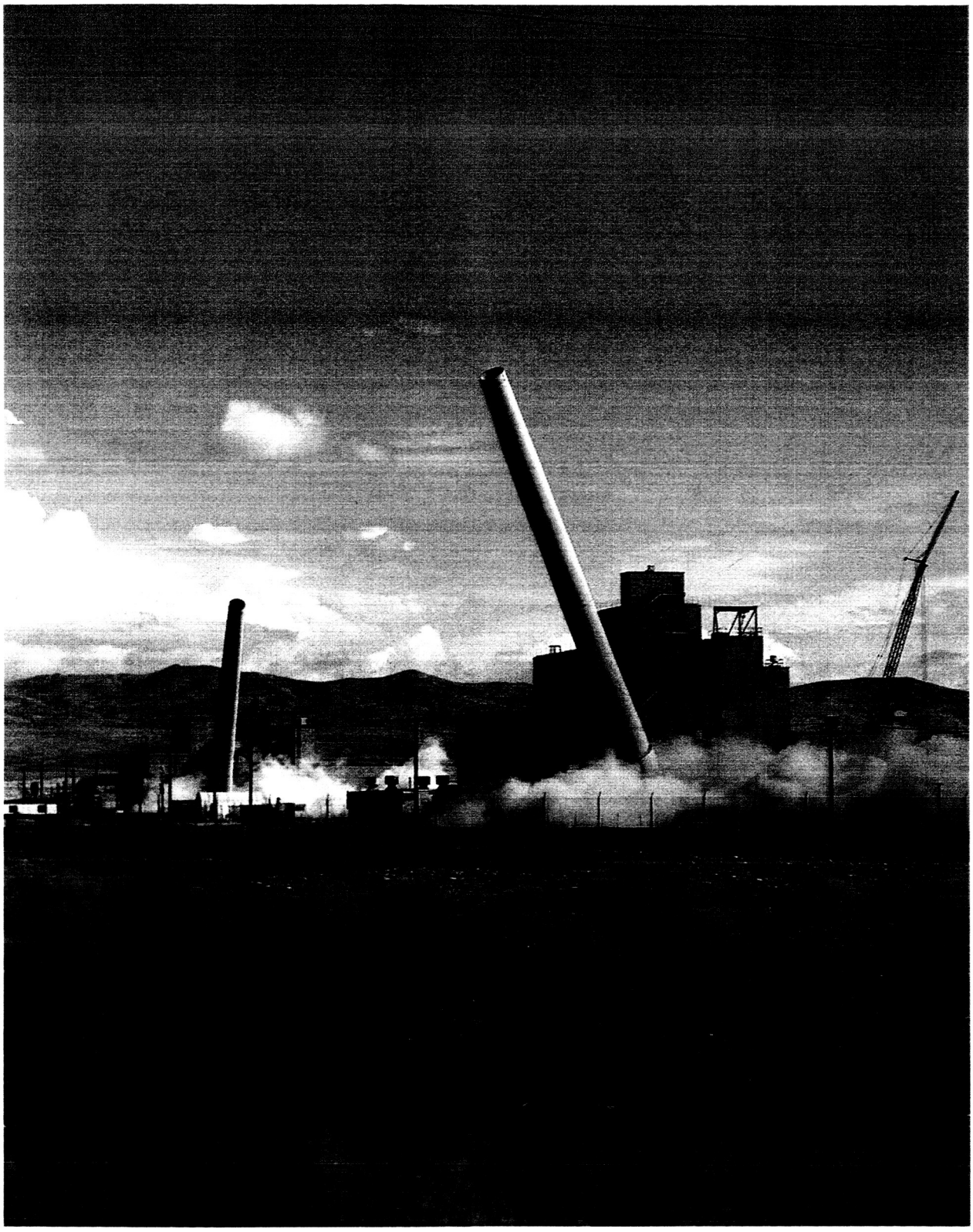


Image 122: Two stacks are felled simultaneously during the decommissioning of the Hanford reactor. In recent years, several other reactors besides Plum Brook have been decommissioned. Successful decommissioning projects include the Watertown Arsenal, Shoreham, the Saxton Nuclear Experimental Corporation, Argonne, Pathfinder, Elk River, Fort St. Vrain, Shippingport Nuclear Power Station, and Trojan. (1977) (Department of Energy Photo 1001138)

Image 123: This calendar, left open in the reactor building just days before the reactor's final closure, has remained untouched for almost 30 years. Despite their disappointment at the shutdown of their facility, Plum Brook employees worked diligently for the next six months to put the reactor into protective safe storage. They hoped that this mothballing procedure would allow the reactor to be reactivated at a future date when research could again be funded. (2001) (NASA C–2001–1182)

"mothballing" procedure was completed. Of the 200 or so Plum Brook reactor employees, the vast majority left NASA. About twenty were sent to Lewis Research Center. Most easily found new work either in other government agencies or in private industry. Their experiences at the Plum Brook reactor gave them valuable skills that were coveted by other organizations. NASA also helped them find new work through elaborate job placement assistance.

The facility was mothballed with such care partly because many of the employees expected that it would reopen again in the near future. Initially, it was thought that the reactor would be used again if the nation revived the human Mars mission in the 1980s. In the meantime, other possible uses for the reactor and the other facilities at Plum Brook Station were explored. In April 1973, a symposium of over fifty scientists, educators, politicians, and economists was held to explore future uses of the station. Their proposals included an industrial park and a multi-university research center. U.S. Representative Charles Mosher pursued several other options. One plan was to convert the reactor into a power facility, but both the AEC and NASA said that was impossible. Another proposal called for using the reactor at a lower power (six megawatts) for continued neutron activation analysis testing for the EPA (which had already

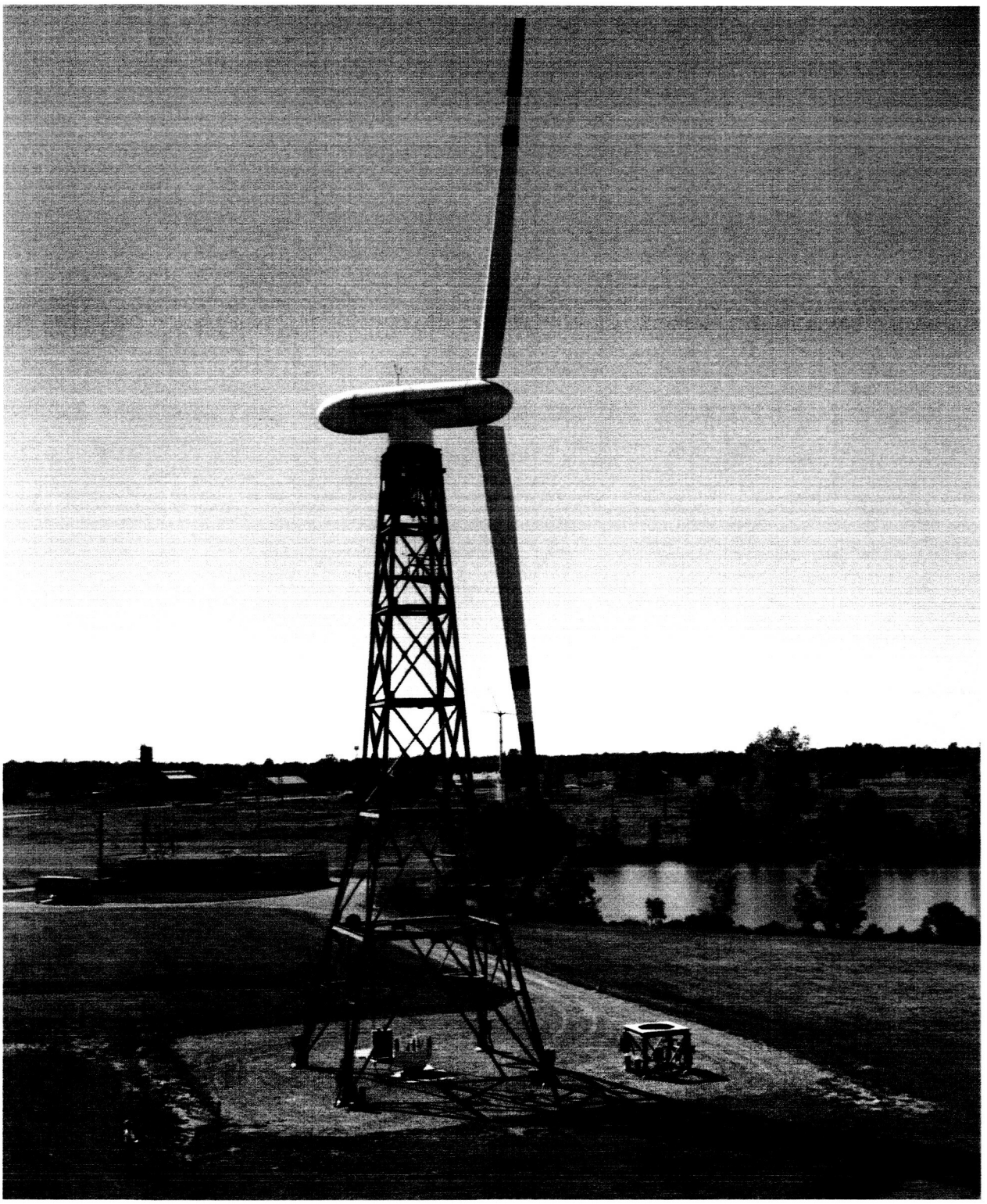


Image 124: Spurred by the energy crisis, NASA, and the Energy Research and Development Administration (ERDA) installed this large 100-kilowatt wind turbine for alternative energy research at Plum Brook. The 100-foot tower supported two sixty-two-foot blades, which could reach forty rpm in eighteen-mph winds. When the Plum Brook reactor shutdown was announced, Congressman Mosher and others endeavored to find alternative uses for Plum Brook Station. The wind turbine was one of the few successful programs on the station in the 1970s and 1980s. By the late 1980s, several of the testing sites at Plum Brook were reactivated and remain in operation today. (28 September 1976) (NASA C–1976–3906)

Image 125: After its mothballing in 1973, the reactor went silent. It was visited only by the numerous deer in the area and a skeleton crew that continued to monitor the facility during the standby period. (NASA C–1961–55643)

been started with experiment 70-08). Dr. James Blue of the NASA Lewis Research Center's cyclotron facility proposed another use for the reactor. At the time, Blue was working with the Cleveland Clinic treating cancer patients with neutrons from the cyclotron. With a ten-year grant from the National Cancer Institute, he helped treat over 4,000 patients at Lewis. He suggested converting Quadrant B at Plum Brook into a medical facility to use epithermal neutrons to treat patients who had brain tumors called glioblastoma.[63] Any decision for future use had to be made before the reactor was to be finally shut down in June 1973. When no decision came about, it became clear that the mothballing procedure was going to be permanent.

During spring 1973 the reactor area was fenced off and locked. The nuclear fuel and wastes were removed, and the still radioactive equipment was placed in the hot laboratories, containment vessel, and canals. The rest of the facility was decontaminated and became subject to NRC licensing. Emergency telephone, water, and electrical systems were retained. The NRC's "possess but do not operate" license required annual renewals, quarterly radiological testing, and regular inspections of alarms and security tools. It also required a staffed communication center, an administrative staff, and the continuation of regular records and reports—enough to keep a skeleton crew at work.

Image 126: For almost thirty years, the facility remained sealed and constantly monitored to ensure that no contamination escaped. However, aesthetic maintenance was not as important, as shown by the peeling paint on the once shiny reactor dome. (1981) (NASA C-1981-4957)

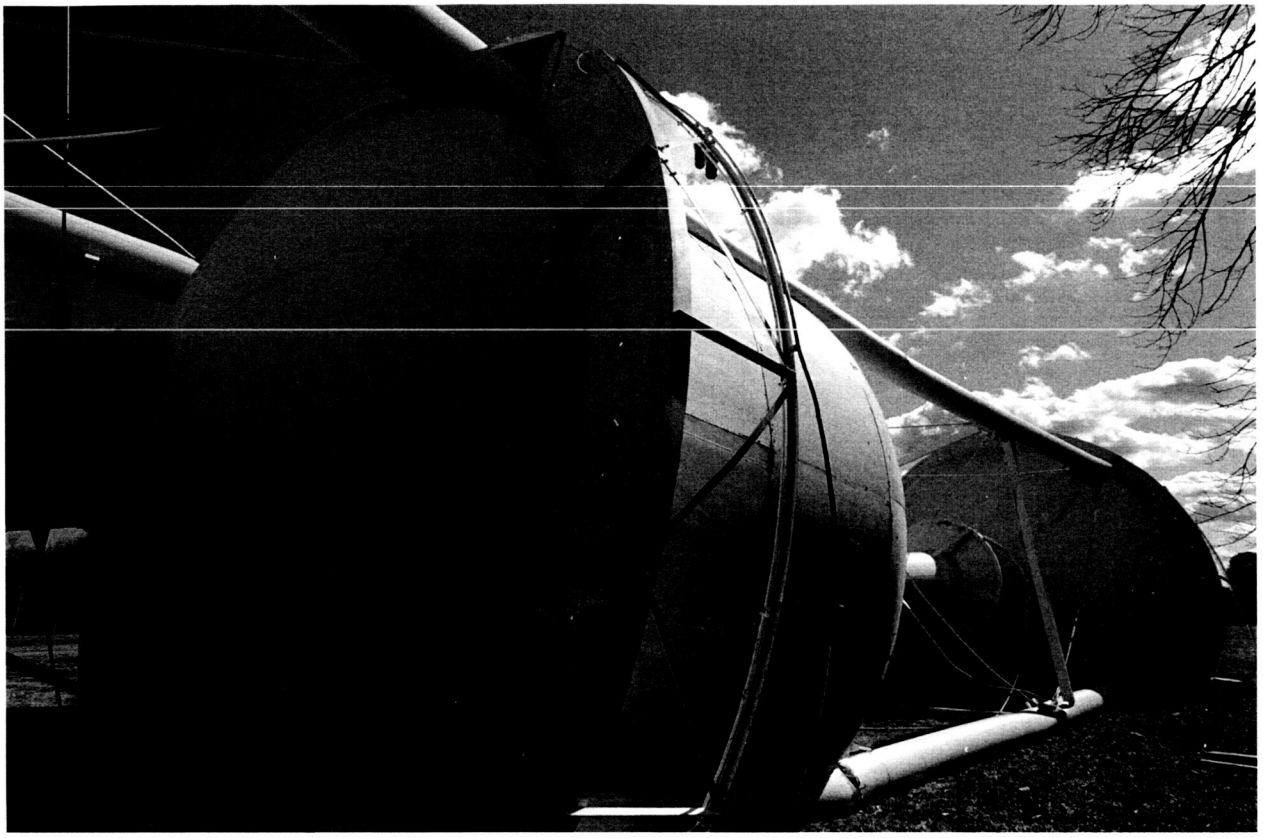
In 1976, a new proposal to NASA headquarters suggested four options for the future of Plum Brook Station. The main recommendation was for an estimated three-year, $1,200,000 reactor-decommissioning project. Decommissioning was considered so costly NASA decided to maintain the reactor in standby mode. The problem was that the costs to keep the facility mothballed rose dramatically every year. In 1979, it was estimated that retaining the reactor in standby condition cost $230,000 annually. Meanwhile, a new 1979 analysis estimated that decommissioning the reactor facility would require six years and $14,744,000. Again, NASA declined to decommission it. Eventually, however, the agency could not ignore the rising costs. NASA knew that it would have to perform this task, and with each year the decommissioning growing more expensive, it finally decided to allocate the funds for the project in 1998.

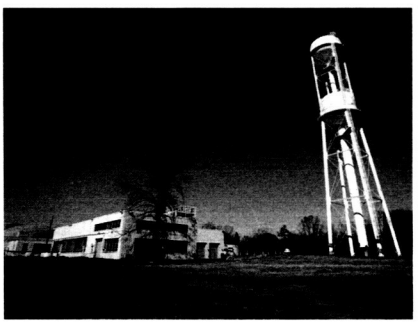
Returning the Land

Visiting the Plum Brook reactor today is like exploring a modern day archeological preserve. It is an eerie Pompeii-like place where the physical remains of the reactor's final hours have been left untouched. Papers remain on desks, paint peels from the walls, calendars stand frozen in time in June 1973, dusty equations linger on blackboards, and tools are still scattered on workbenches. Numerous ashtrays, some built into the testing machines themselves, bear the scars of thousands of cigarettes ground into them over the years. Posters from J. Edgar Hoover and the FBI continue to admonish, "A theft from your government is a theft from YOU!" In contrast to the artifacts that were left haphazardly forgotten, meticulous attention was given to maintaining the reactor core and ensuring its environmental safety. It is a testament to the scientists and engineers who were responsible for closing down the reactor that none of its structures began to physically deteriorate and endanger the surrounding community.

The reactor remained in this mothball state for a quarter century until it opened once again, but this time not for research. In 1998, NASA requested annual renewal of its "possess but do not operate" license from the NRC. The NRC responded by asking NASA to consider decommissioning the entire reactor because it was becoming increasingly expensive to maintain the facility and the half-life of many of the isotopes had lapsed, making it safer to tear down. NASA agreed and approved the funds to dismantle the facility with a projected completion date in 2007. In December 1999, NASA submitted a decommissioning plan to the NRC.[64]

The plan described an extensive decommissioning process through which, piece by piece, the entire building would be dismantled. Engineers planned to transform the 117-acre site into an empty field, with an assurance to environmentalists that the ground would be safe enough for a family to actually live on the land, grow crops on





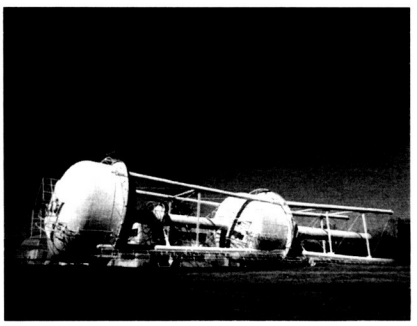


Image 127: Despite the fact that decommissioning work had been on-going since 2001, the felling of the 193-foot-tall double water tower was one of the first external signs that the Plum Brook reactor was being dismantled. The tower stood adjacent to the Reactor Facility from 1959 until its demolition in October 15, 2003. Workers placed explosive charges on the legs of the tower to collapse it in a controlled manner. The felled tower was then cut into pieces and shipped offsite for disposal. (NASA C-2004-742), (NASA C-2004-743), (NASA C-2004-744), (NASA C-2004-745)

Image 128: Above, Dean Sheibley and Barbara Johnson perform studies in the Plum Brook chemistry lab in 1961 before the reactor was shut down. (NASA C-1961-55639)

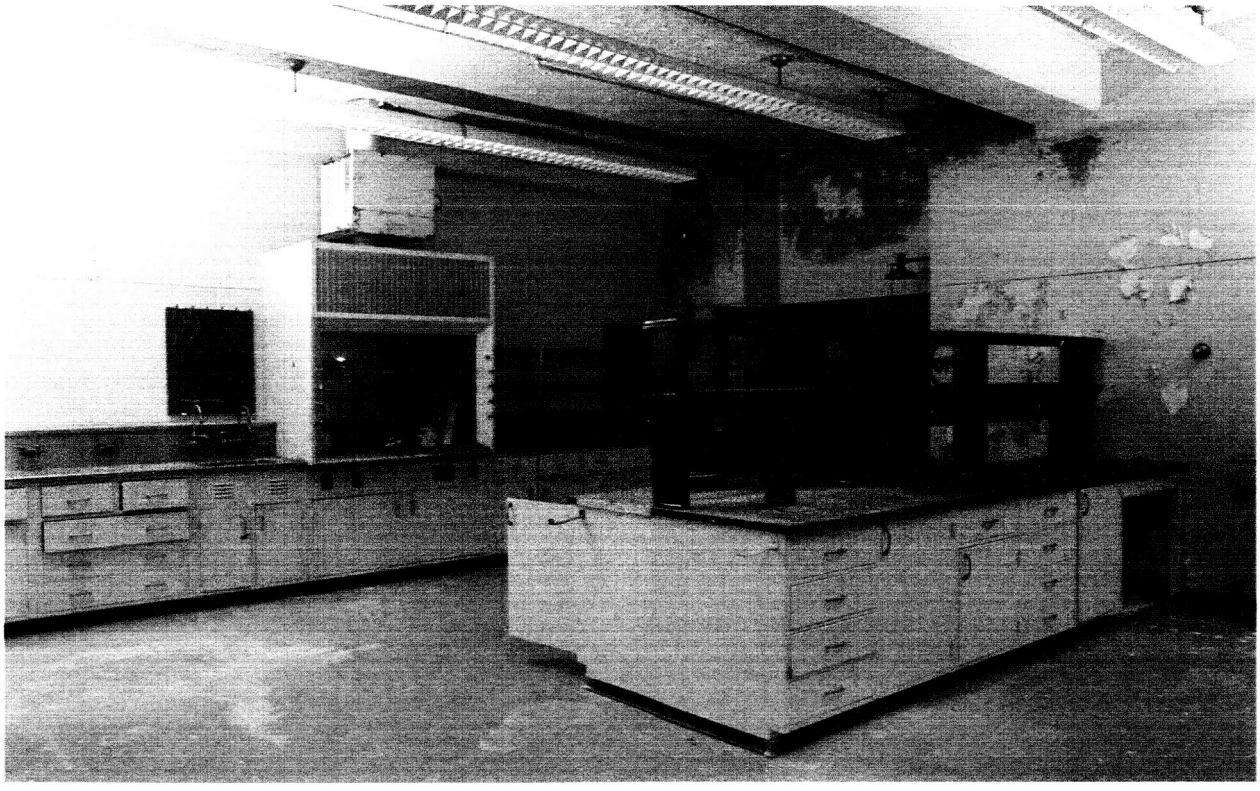


Image 129: The chemistry lab forty years later, in 2001. The Plum Brook reactor, once a lively research center, had become a ghost town. (NASA C-2001-1173)

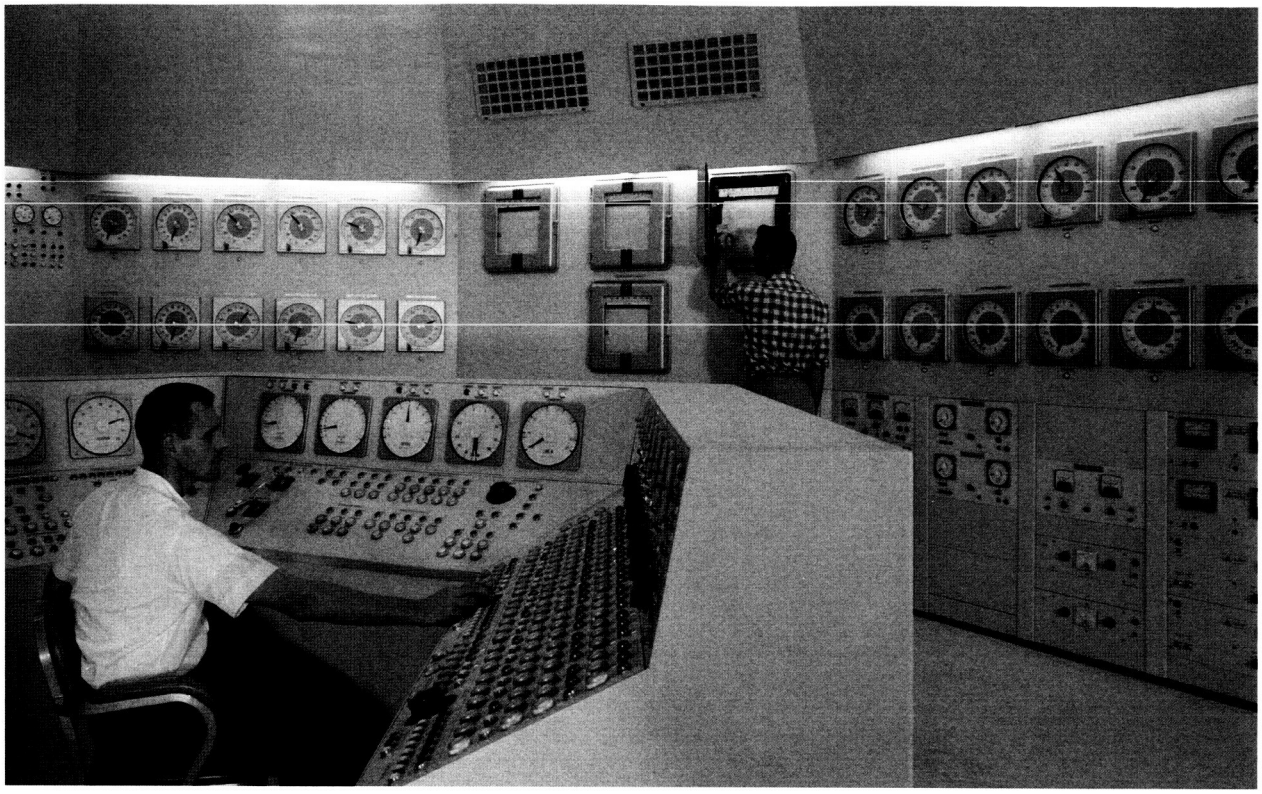


Image 130: Bill Fecych (seated) and Don Johnson work in the reactor control room during its operating days in 1959. After an ad hoc committee study in 1977, NASA Headquarters decided that the reactor would never be put back into operation. Reactor equipment was then "cannibalized" for other programs. (NASA C–1959–51506)

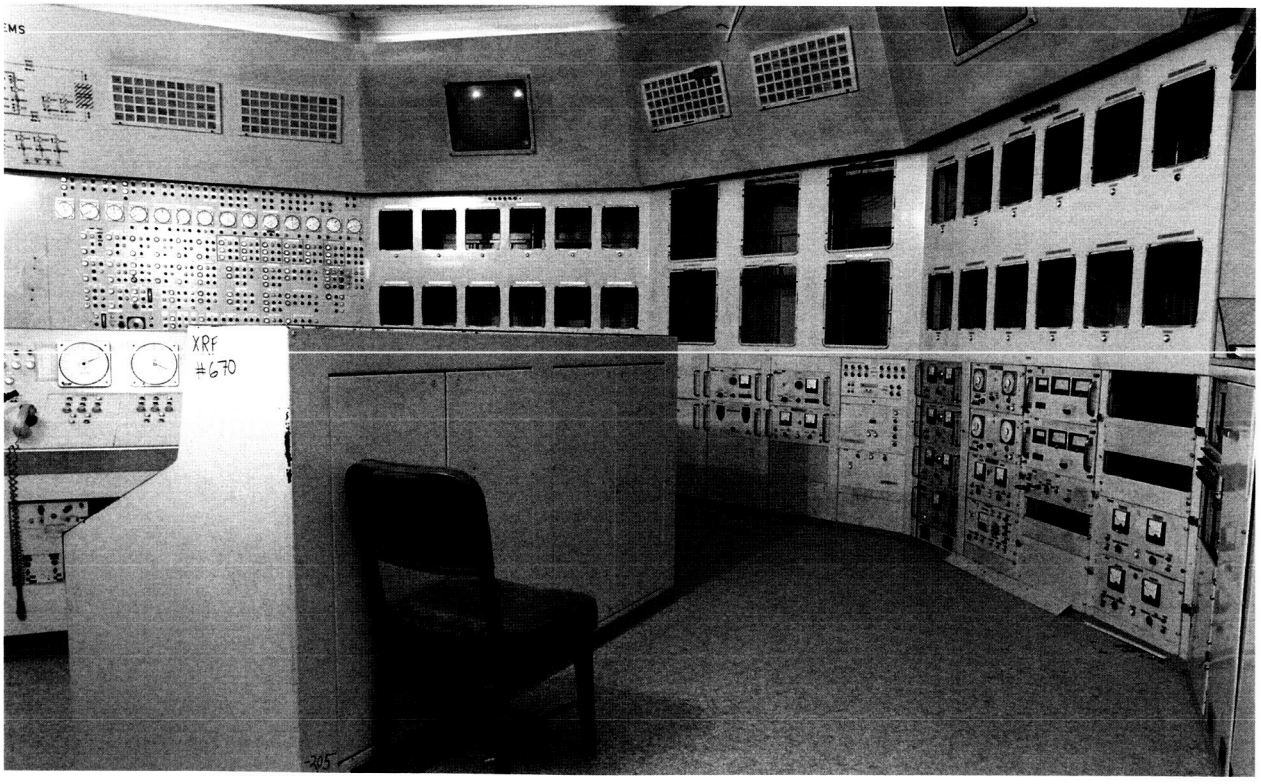


Image 131: The Plum Brook reactor control room in 2001, stripped of a significant amount of its instrumentation. (NASA C–2001–01221)

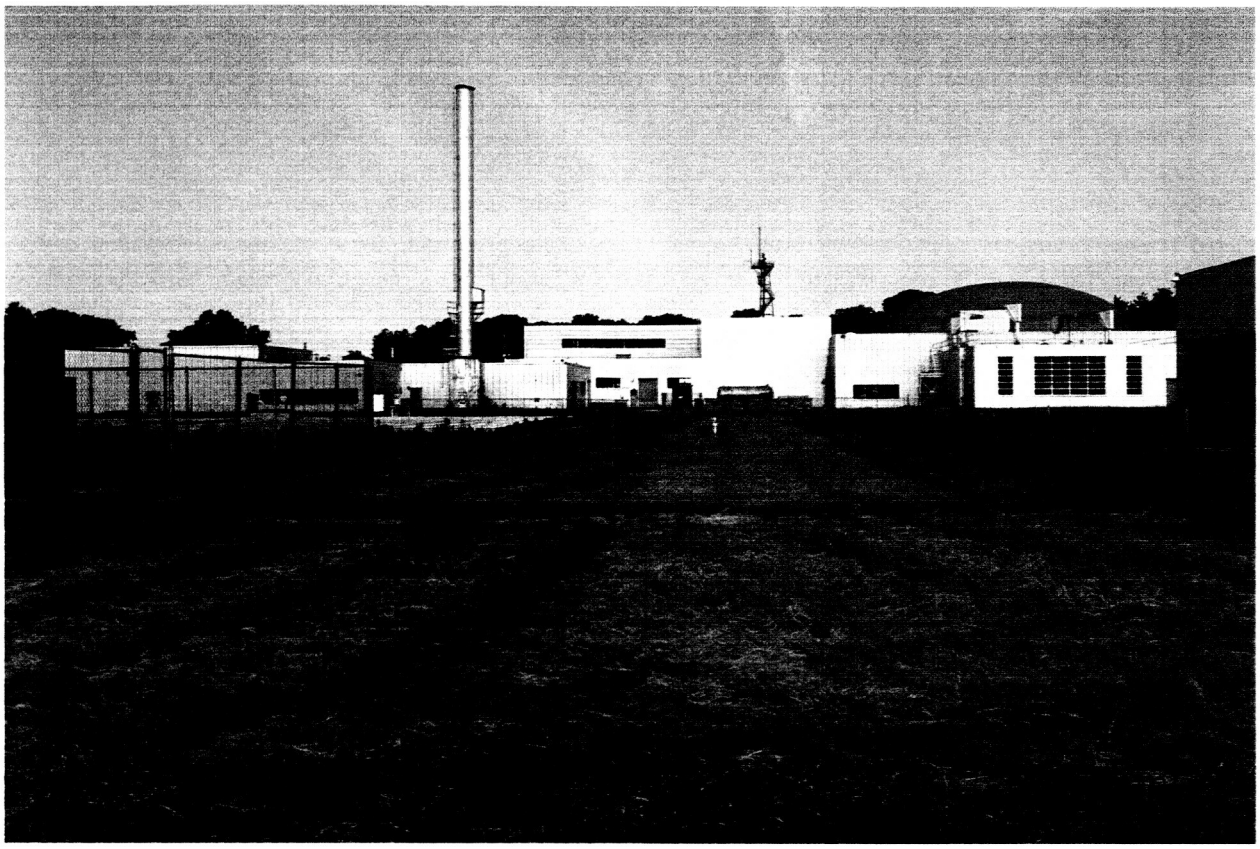


Image 132: Above, after serving as the site for the Ordnance Works pentolite production facility and the NASA reactor for over sixty years, this land will be restored by the decommissioning process to a condition safe enough to allow crops to be grown upon it again. (NASA C–2001–01214)

Image 133: An existing natural field at Plum Brook Station. (NASA Glenn Environmental Management Office)

Image 134: Decommissioning manager Tim Polich (second from left) and Keith Peecook (right) consult with former reactor employees Jim Martz (left), Len Homyak (third from left), and Jack Crooks (second from right). Retired Plum Brook employees have assisted the decommissioning team throughout the decommissioning process. (2002) (NASA C-2002-1023)

it, drink water, and raise livestock.[65] Great care would be taken to decontaminate everything that came into contact with radiation before being transported to landfills in Utah and South Carolina. Keith Peecook, senior project engineer, observed, "It's not just going in with a wrecking ball, it's a little more surgical in nature."[66]

The cornerstone of the plan was a federal partnership between NASA, the U.S. Army Corps of Engineers (USACE), and Argonne National Laboratories (a section of the U.S. Department of Energy). USACE was an important partner because it had extensive experience managing large cleanup and construction projects. It also served as an important link to expertise in the private sector. USACE hired Montgomery Watson Harza from Pasadena, California, as prime contractor for the project. Duke Engineering Services from Charlotte, North Carolina, and MOTA Corporation from Columbia, South Carolina, were also chosen as subcontractors to assist with the engineering challenges.[67]

Despite the importance of the team, NASA was the organization that was ultimately responsible for the decommissioning process. Tim Polich left the NRC to become NASA's decommissioning manager in 1999. He and his team became responsible for overseeing the entire process, which is sometimes conceptualized as construction in reverse. Unlike conventional building from the

Image 135: In September 2002, Plum Brook Station held its third reunion for former employees. About 250 people attended. While the reactor itself was closed because of the decommissioning process, most of the retirees did not even visit the site's exterior because they wanted to remember the way it was, and not in its current state of disrepair. (NASA C-2002-01879)

ground up, Polich and his team are literally proceeding from the roof to the ground. This includes removing and safely disposing all radioactive materials, decontaminating and demolishing all of the buildings at the site, and finally backfilling the entire area with clean fill dirt. On 21 March 2002 the NRC officially approved the decommissioning plan. NASA Glenn Research Center director Donald J. Campbell said that the NRC approval of NASA's approach "reflects confidence in the capabilities and experience of our project team... The pre-decommissioning activities to date were just the beginning; now the real work begins."[68]

Throughout the decommissioning process, safety issues continue to be a primary focus to protect the workers, the surrounding community, and the environment. Tim Polich affirmed that "NASA is committed to the safest method of decommissioning these reactors."[69] Every worker and visitor to the reactor is given extensive training and must pass a test to prove awareness of radiation safety issues. Everyone who goes inside the reactor carries a personal dosimeter, which indicates an unplanned exposure to radiation. Also, upon leaving the reactor, everyone must pass through full-body radiation monitors to detect any trace amounts of contamination.

The nearby community is kept informed through the Multifaceted Community Relations Plan, which was established to educate the public about decommissioning activities. It also conducts extensive research with people from the surrounding area to ensure that they understand what is happening behind the secured Plum Brook fences.

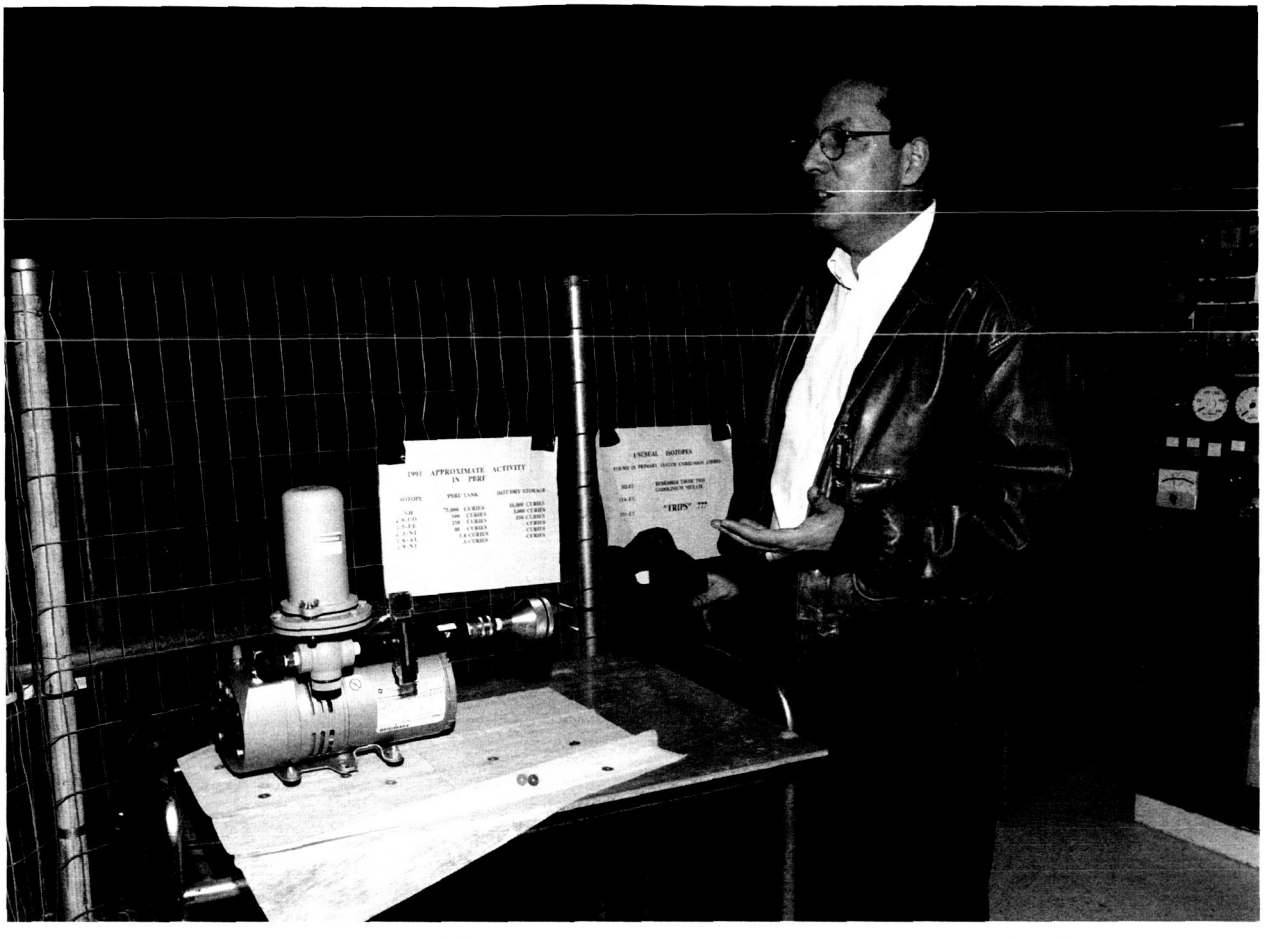


Image 136: In April 2002, Keith Peecook led the Decommissioning Community Workgroup on a tour through the reactor facility. The tour was designed to demonstrate the safety measures in force during the decommissioning process. (NASA C–2003–852)

NASA assures the community that any family living in the area will receive no more than a dose of twenty-five millirems of radiation per year because of their proximity to the reactor. Ohio residents on average receive about 360 millirems per year from the sun, and the government has limited the radiation dose that a worker may receive on the job during any year to no more than 5,000 millirems. Those who work at the site every day during a year will likely receive only about one-fifth that amount.

Environmental precautions are also rigorously followed. Every week air samples are taken, and water samples from the area are collected every month for analysis at an offsite laboratory. The Plum Brook decommissioning is considered NASA's largest environmental project, not only because of the importance of safely disposing of radioactive remains, but also because the surrounding area is a unique natural preserve.

Despite being home to the production of nearly one billion pounds of gunpowder during World War II and two nuclear reactors since 1961, much of the protected area inside the Plum Brook fences remains remarkably unspoiled. Today Plum Brook's 6,400 acres of land demonstrate an incredible ecological variety and vitality, including 521 plant, 125 breeding bird, 21 amphibian/reptile, 16 fish, 53 butterfly, 450 moth, and 8 bat species. Several of these are protected by the Endangered Species Act, which maintains that federal agencies cannot jeopardize the existence of any threatened spe-

Image 137: This swampy wetlands area is home to a Saturated Shrubland Alliance of dogwoods and willows. Plum Brook Station's approximately 5,400 acres contain a wide variety of wildlife and natural habitats, including fields, meadows, forests, and wetlands. (NASA Glenn Environmental Management Office)

cies. Plum Brook has 20 plant, 8 bird, 3 amphibian/reptile, and 1 moth protected species. Eleven populations of Least St. John's Wort grow at Plum Brook, which represents the largest concentrations of this plant in Ohio. The Sedge Wren uses the area as one of the most important breeding grounds for its species. In recent years a Bald Eagle pair built a nest at the facility and onlookers were treated to the rare sight of baby eagles.

The Plum Brook forests and plains are also unique. The central meadows area is significant because Ohio has no other native prairie locations like it. Though the presence of humans has restricted its natural growth, through proper cultivation it has great potential to be restored to its original condition. The west area native forests are also important. According to Mike Blotzer, chief of the Environmental Management Office at Glenn Research Center, "[The region] may be one of the most significant remnant forest areas in the Ohio Lake Plain. It is unique as a remarkable representation of Ohio forest conditions at the time of the early settlement in the early 19th century."[70]

Ironically, the land the government forcibly acquired through eminent domain in 1940 for use as an ordnance works—and later as the home of NASA's most powerful nuclear test reactor—will once again be restored to its natural condition. From the natural frontier, to the nuclear frontier, and back again, the Plum Brook land demonstrates the resiliency of nature and its adaptability to modern development. But what must not be forgotten is that without the emphasis on safety and environmental preservation by NASA's scientists and engineers, the dangers of nuclear research might have forever contaminated an important piece of our American heritage.

Image 138: Ashy sunflower plants are scattered around Ohio, but the Plum Brook Station probably has the state's largest natural population. A 1994 survey found the population near the intersection of Fox and Patrol Roads had been decimated by deer grazing. No flowers or fruits were observed that year, but the species had recovered dramatically by 2001, apparently due to the deer management that has been practiced within the facility. (NASA Glenn Environmental Management Office)

Image 139: Despite being cleared and drained for farming long before World War II, Plum Brook Station contains a wide variety of forest areas. This seasonally flooded Forest Alliance of pin oaks, and the many other wooded areas, are no more than sixty years old—and may be younger than that. (NASA Glenn Environmental Management Office)

Image 140: Plum Brook Station's protected fence line has created a sanctuary for a plethora of wildlife populations. The deer population inside the fence is often in excess of 2,000. Controlled hunts are occasionally scheduled to keep the number of deer in proportion with a sustainable habitat. (NASA C-2003-853)

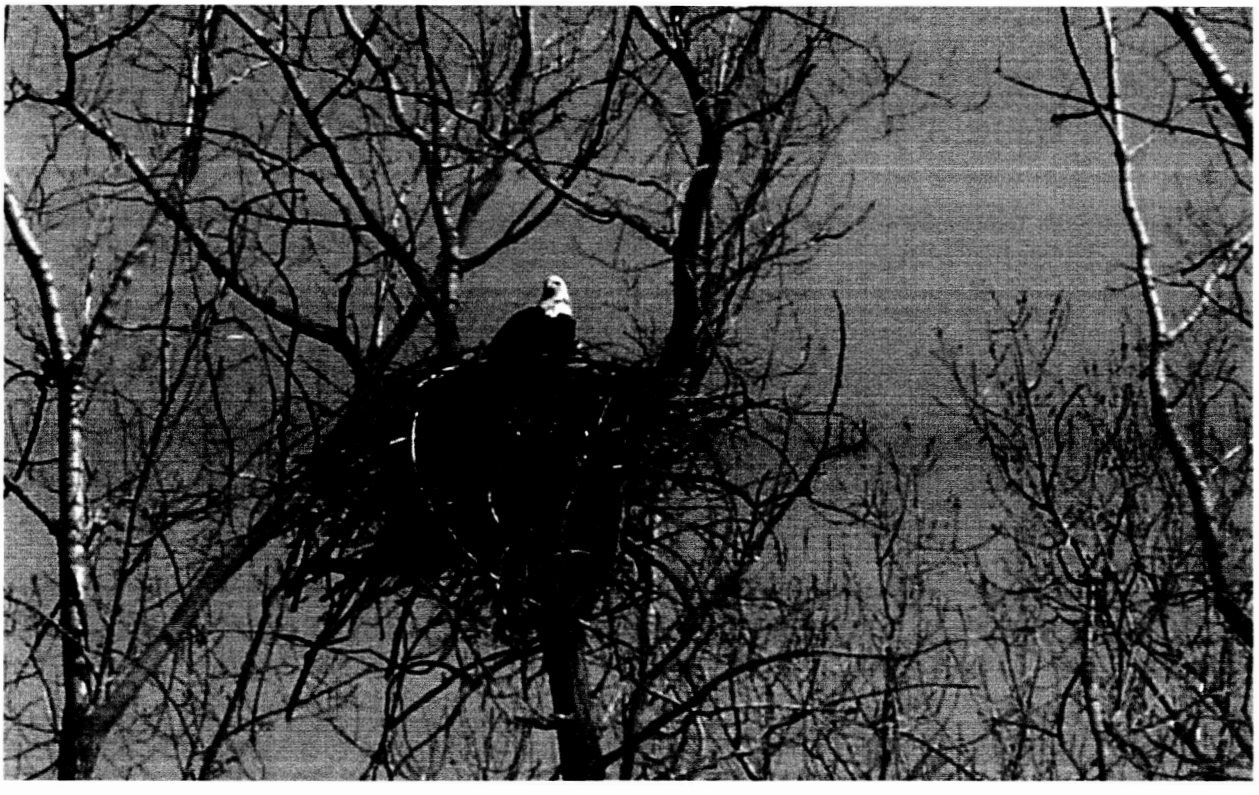


Image 141: In recent years, Bald Eagles have been observed nesting at Plum Brook. (NASA C-2004-771)

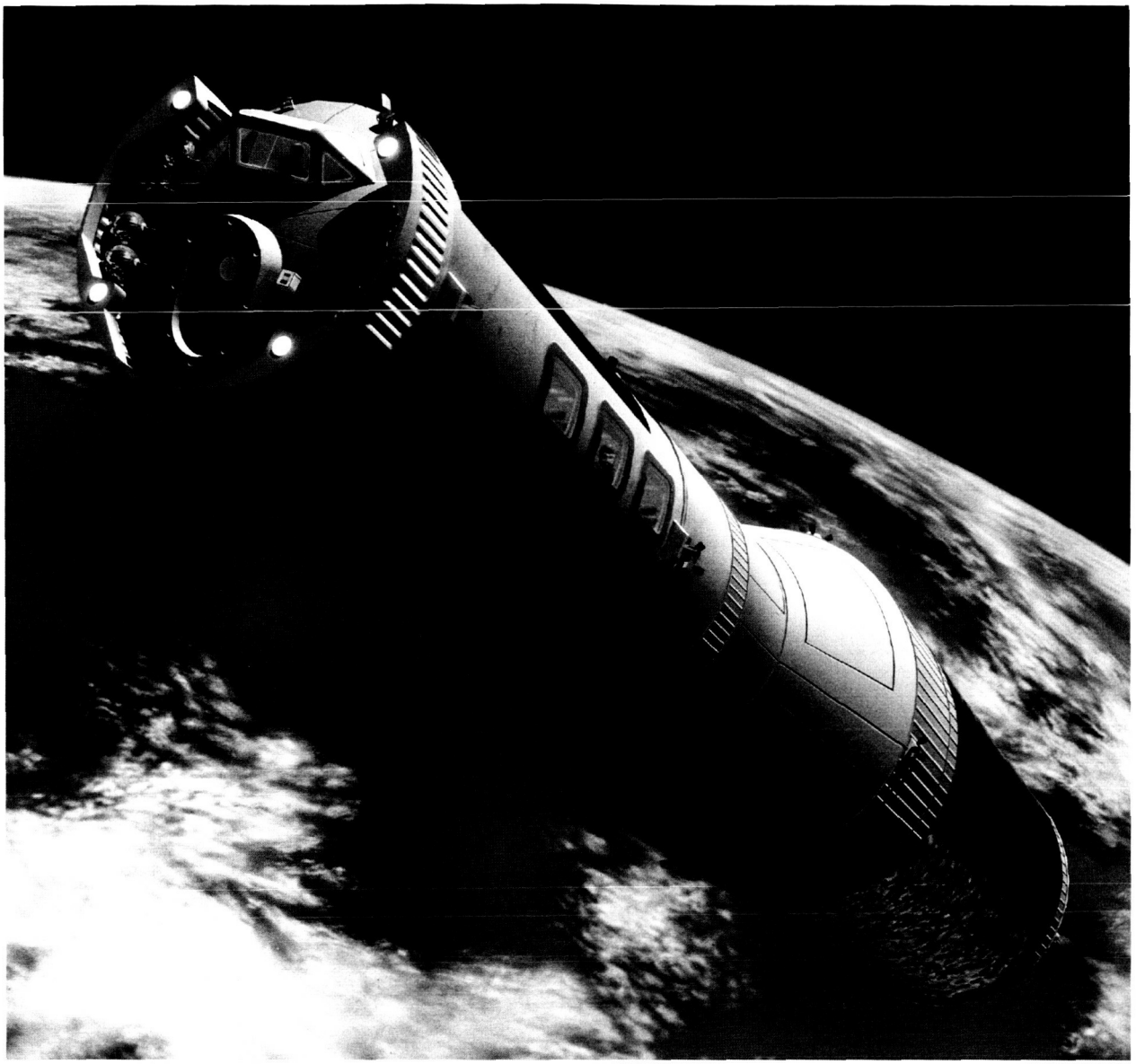


Image 142: Artist's rendering of a nuclear rocket capable of reaching the Moon in 24 hours. This image was developed for NASA by Pat Rawlings and Bill Gleason (SAIC). (NASA S99-04186)

Though Kennedy's dream of a nuclear rocket went unrealized in the 1960s, it has now become one of NASA's most pressing goals for the future. NASA is revisiting the advantages of designing and constructing nuclear rockets for space exploration and an eventual human voyage to Mars. NASA Administrator Sean O'Keefe outlined NASA's new nuclear vision for the future in April 2002, which includes the launch of space probes to the outer solar system.

After Plum Brook's shutdown, few other reactors continued to study the effects of radiation on materials in space. In the end, Plum Brook's basic research into the effects of radiation on materials may serve as an important starting point for the rejuvenated nuclear program. Many of the materials that might be used for the new nuclear initiative were originally tested in the Plum Brook reactor decades ago. Though the reactor is now quiet, its archived data can be resurrected and put to use as America begins a renewed quest to explore the frontiers of outer space with nuclear rockets.

Primary Document #7

NASA Administrator Sean O'Keefe delivered his vision for the future of NASA on 12 April 2002 at the Maxwell School of Citizenship and Public Affairs, University of Syracuse. He recommitted NASA to pursuing a nuclear rocket as the best hope for exploring the solar system. The following is an excerpt of that speech, focusing on his plans to develop nuclear rockets.

"PIONEERING THE FUTURE"
Sean O'Keefe
NASA Administrator
April 12, 2002

...In broad terms, our mandate is to pioneer the future, to push the envelop, to do what has never been done before. An amazing charter indeed. NASA is what Americans, and the people of the world, think of when the conversation turns to the future.

...What NASA needs now is a roadmap to continue our work in a more efficient, collaborative manner. Our imperative is not only for the sake of knowledge—it is for our future and our security. Today I am introducing a new strategic framework and vision for NASA. It is a blueprint for the future of exploration.

...NASA has to do things differently in the future. One fundamental difference is a need to find new ways to explore the galaxy. Conventional rockets and fuel simply aren't practical as we reach further out into the cosmos. That's why we are launching an initiative to explore the use of nuclear propulsion.

One of the major obstacles of deep space travel is finding fast and efficient ways to get around, to get to anywhere. Today's spacecraft travel at speeds slightly faster than John Glenn's Friendship 7 did 40 years ago. NASA has explored the use of solar sails and ion engines as alternatives to conventional fuels, but their uses are limited and restricts us to very close-in objectives, or if used for deep space exploration, require us to wait a long time before we see results—a minimum of 10 years for example, to get to the edge of our own solar system, and a lot longer if we miss the "sling shot" effect of optimum planet alignment. So the nuclear propulsion initiative is the next logical step to overcome this technology limitation. It's a mature technology and its application to space travel has great potential. The U.S. Navy has been operating nuclear powered vessels since 1955. In that time, the Navy has sailed more than 120 million miles without incident, and has safely operated these efficient power generators for more than 5000 reactor-years. And throughout that time, the Navy has designed more compact, safer, and more efficient reactors, which last the 40-year life of the vessels without refueling.

The technology is there. We just need to take it to the next step to increase speed and on-orbit time, thereby beginning to overcome this persistent technical limitation. If we're going to pioneer the future as only NASA can, we're going to need new ways to get us there.

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Appendices

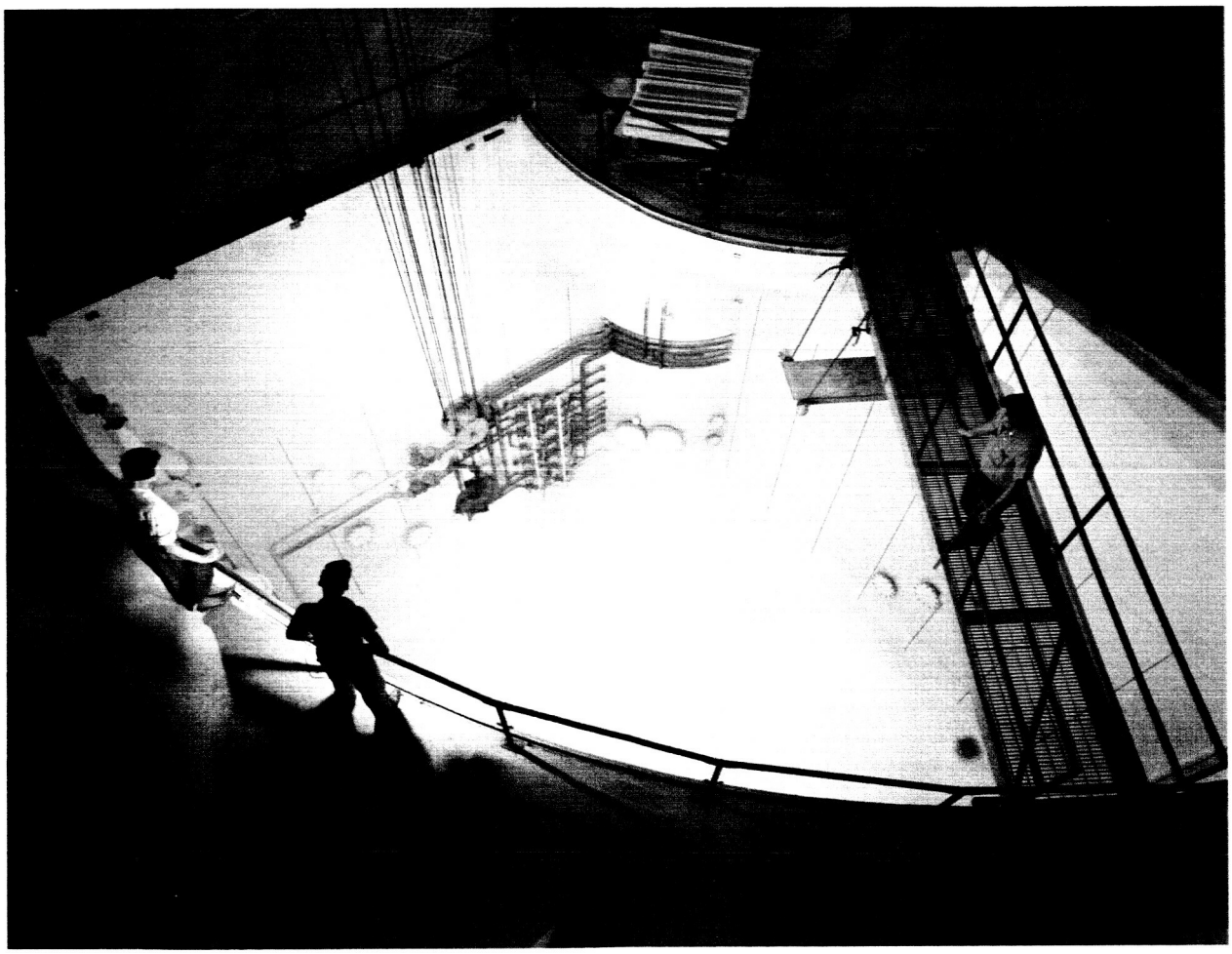


Image 143: Gazing into the abyss, employees soak up the quiet calm of the Plum Brook reactor at night. Many times on the overnight shift, the operators would turn off the overhead lights in the control room and work by the glow of the indicator lights. In addition to having a soothing effect, this also brought out the indicator colors, so if there was any abnormality it jumped right out at the operator. Music was also piped into the control room. (1959) (NASA C-2003-852)

Timeline

1941 In January, U.S. Army announces Plum Brook site selection for an Ordnance Works (9,000 acres). It begins buying options on properties and town meetings are held. In March, the remainder of deeds are purchased. Residents are given until April to vacate. In April, E.B. Badger & Sons begin construction. In September, a dedication ceremony is held. In November, Plum Brook's first trinitrotoluene (TNT) production line begins operation, twenty-two days before Pearl Harbor is attacked by Japan.

1942 In August, Abbott & Costello visit Plum Brook Ordnance Works as part of war bond campaign.

1943 In April, the B-17 bomber bought with Plum Brook bonds is christened the Plum Brook Trojanair. The first research reactor is built at the University of Chicago.

1945 In May, Germany surrenders; in August, Japan surrenders. Plum Brook ceases producing munitions. In December, Plum Brook land is transferred from Trojan to the Army.

1946 War Assets Administration accepts custody of Plum Brook. The Atomic Energy Commission (AEC) is founded.

1947 Magazine area is renamed the Plum Brook Depot Activity.

1949 In May, NACA Lewis Laboratory acquires cyclotron for basic materials research. The Plum Brook land is transferred to the General Services Administration.

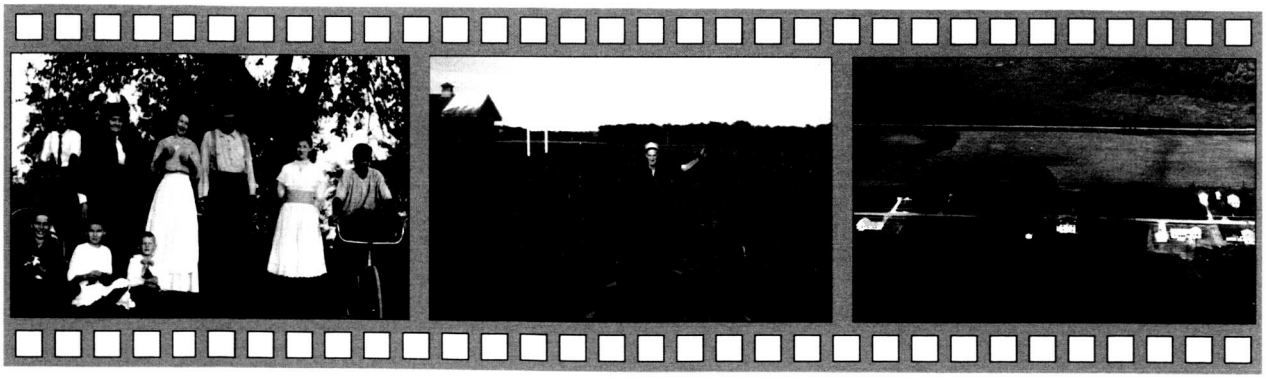
1951 NACA begins examining requirements to build research facilities and test nuclear engines for airplanes.

1952 In March, the Materials Test Reactor at Idaho Falls sustains its first nuclear reaction. It will serve as a model for the Plum Brook Reactor Facility.

1953 President Eisenhower delivers "Atoms for Peace" speech to the United Nations General Assembly.

1954 In January, the USS Nautilus, the world's first nuclear submarine, is christened. Nuclear school begins at Lewis. Army reacquires Plum Brook from General Services Administration; it becomes a satellite of the Ravenna Arsenal for the Korean War.

1955 Nuclear space initiative begins with two primary programs: Nuclear Engine for Rocket Vehicle Application (NERVA) and Space Nuclear Auxiliary Program (SNAP). NACA proposes concept of nuclear reactor facility to AEC. Site Survey for NACA Research Reactor published (September 13), and Plum Brook site is chosen. Congress approves construction of sixty-megawatt reactor. A B-36 bomber begins forty-seven flights over Texas with a nonpropulsive test reactor aboard.



1956 AEC announces testing in Idaho on stationary forerunner of the atomic aircraft engine. The NACA is given permission to use 500 acres for Plum Brook reactor. In September, ground is broken for the Plum Brook Reactor Facility. In October, NACA Reactor Facility Hazards Summary is submitted to AEC.

1957 In October, the Soviet Union launches Sputnik.

1958 In January, the Army transfers 3,180 acres to NACA for a five-year period. In March, the Plum Brook area is released from the jurisdiction of the Ravenna Arsenal. In June, 65 percent of the construction is complete. In October, the NACA transforms into NASA.

1959 In December, an updated Final Hazards Summary is submitted to the AEC.

1960 Provisional operating license is issued by the AEC. The joint AEC-NASA Space Nuclear Propulsion Office (SNPO) is formed. SNPO is given the responsibility to build the NERVA, the first nuclear rocket engine.

1961 In March, President Kennedy terminates the nuclear airplane program. In May, Kennedy lends support to the nuclear rocket program in his "Urgent National Needs" speech. Low-power testing is performed at Plum Brook in June. On 14 June 1961, the Plum Brook test reactor goes critical for the first time.

1962 In May, the United States Congress approves $40 million expansion program for Plum Brook in the next fiscal year.

1963 In April, the reactor reaches full sixty-megawatt power for the first time. In July, it reaches criticality for its first experimental cycle, which is completed on August 15. Also in July, the Mock-Up Reactor (MUR) receives its license from the AEC. The MUR begins operation on September 5 and goes critical for the first time on September 10. In October, over 1,600 people visit the Plum Brook reactor during a public relations event. In December, the hot laboratory becomes operational.

1964 Plum Brook reactor completes its first year of operation at full power. The first fueled experiment is run in the reactor in August.

1966 The Plum Brook reactor completes its 50th cycle.

1969 The Plum Brook reactor completes its 100th cycle.

1970 The reactor begins investigations for the Environmental Protection Agency.

1972 In December, the last astronauts walk on the Moon with Apollo 17.

1973 In January, NASA Lewis director Bruce Lundin announces immediate shutdown of reactor. All experimental programs end that day. By June, "mothballing" of the reactor is complete.

1974 Bob Didelot begins work as standby manager; he maintains this job until 1980. The AEC is suspended and becomes the Nuclear Regulatory Commission (NRC).

1976 Four future uses for the Plum Brook reactor are suggested to NASA headquarters.

1977 The decision is made to not restart the reactor. Reactor equipment begins to be cannibalized by other programs.

1978 Teledyne performs a decommissioning options study.

1980 In January, a decommissioning project office is established at Lewis Research Center. In March, NASA submits a five-year dismantling plan to the NRC. In September, Earl Boitel becomes new Plum Brook reactor standby manager.

1981 In May, the order to dismantle is not carried out for budget reasons.

1983 In April, the Plum Brook Procedures Manual is completely rewritten to reflect pre-dismantling work. Radiological surveys are performed on the cooling tower and disposal basins. In July, the reactor cooling tower is razed and burned.

1984 The Plum Brook reactor is granted a "possess but do not operate" license.

1985 In January, cracks in pipes allow liquid to leak into basement of the hot lab. In July, NASA requests a return to "possess but do not operate" license and rescinds dismantling order. In October, Hank Pfanner becomes new standby manager.

1987 In January, a "possess but do not operate" license is reinstated for a ten-year period.

1989 In March, Sverdrup Technology, Inc., assumes control of maintaining the reactor and operating test sites.

1996 A $900,000 maintenance project performed.

1999 In December, NASA submits its decommissioning plan to NRC. Tim Polich becomes NASA's decommissioning manager.

2002 In March, NRC approves the Plum Brook plan and decommissioning starts. In April, NASA administrator Sean O'Keefe outlines a new vision for a nuclear rocket.

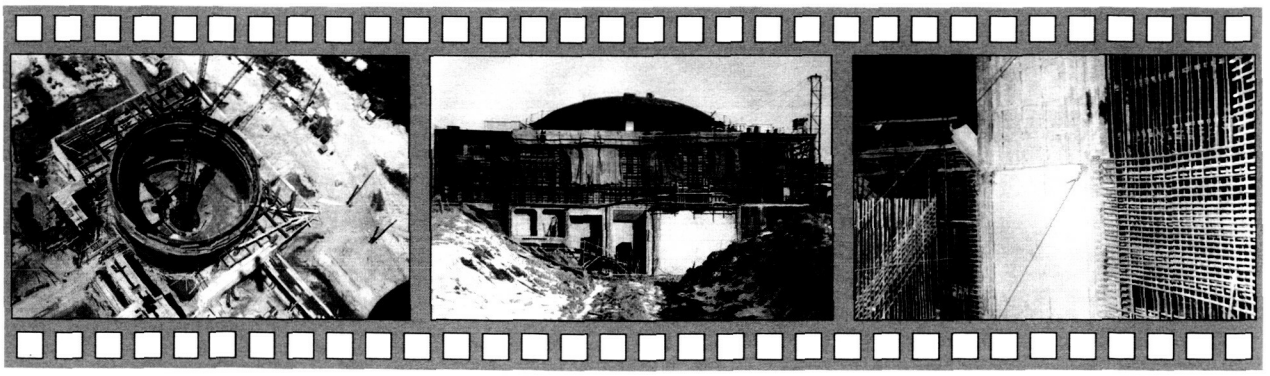
2007 Projected completion date for Plum Brook reactor decommissioning.

Reactor Experiments

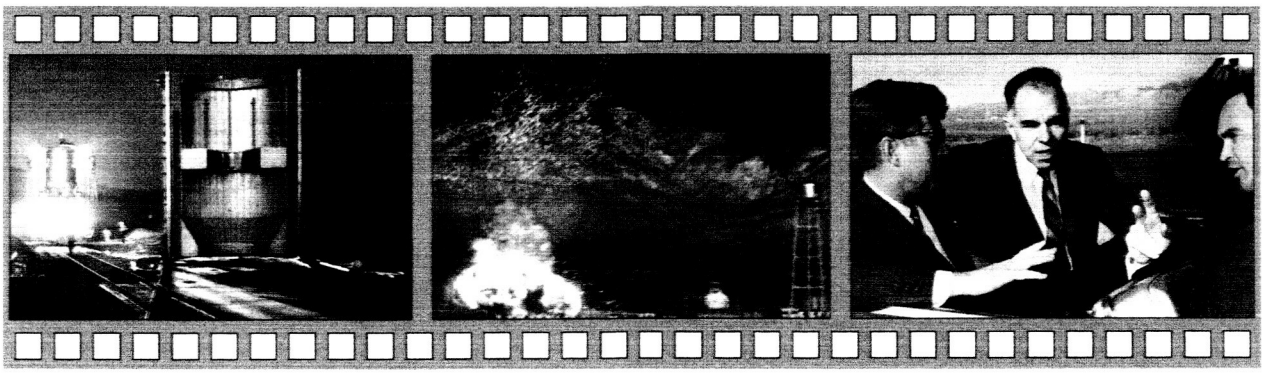
Note: Data from this table was compiled from the 152 reactor-cycle reports located in the NASA Plum Brook Station Library. The cycle column refers not only to when the experiments were in the reactor, but also indicates when preparatory work began in setting up the equipment.

Exp. Number	Cycles	Name	Description
62-01	3,5–84	Lockheed Cyrogenic Experiment	Determined the effects of radiation on materials at cryogenic temperatures.
62-02	36–52 54–63, 75	In-Pile Helium Cooled Loop	Aided in evaluating loop performance under gamma heating on the in-pile experiments. A great deal of effort went into preparing equipment for this type of experimentation.
62-03	3–11 30, 31, 33–45 58–61, 64, 75–79, 83–88, 92–94, 96–100 102–103	Neutron Scattering and Diffraction Experiment	Provided a collimated beam of gamma and neutron radiation for use by experimenters.
62-04	76, 78–152	Irradiation of Solid Film Lubricants	The experimental data for this test was programmed on the EDLAS computer. Utilized a collimated beam of thermal neutrons emerging from HB-4 to con duct experiments in basic physics, and more specifically in neutron diffraction studies. For example, during one cycle fifty-two data point runs were made with a barium chlorate monohydrate crystal. During another, ninety-three data points were made with a calcium bromate monohydrate crystal.
62-05	19, 21–31, 33–91 93–111	Neutron Diffraction	

Exp. Number	Cycles	Name	Description
62-05R1		Interim NERVA Irradiation	Modifications to the previous experiment were made to improve the reliability of the system.
62-06	30, 45–49 55–75	General Electric NERVA Actuator	After a great deal of setup time, in November 1967 drum actuator type AG20 was irradiated for sixty-five minutes at sixty megawatts of power.
62-07	3, 5–8, 12–15, 19–24, 30	Mallory and Tungsten Irradiation	Determined the radiation effects on material properties and corrosion resistance of Mallory 1000 and pure tungsten.
62-07R1	76–78	Radiation Effects on Material Properties of Tungsten	A capsule that contained thirty tungsten tensile test specimens was irradiated.
62-09	3	PB Space Propulsion Facility Activation Measurement	Determined the optimum material composition for walls at Plum Brook's Space Propulsion Facility. Rabbits were irradiated with samples of unclad and cadmium-clad 304 stainless steel, and unclad and cadmium-clad 5083 aluminum.
62-12	19, 21, 23–45 49, 51–53, 55, 62, 63, 65, 70–72 76, 79, 91 96–100, 102–104, 108, 109, 111, 118, 146	Fueled Material Specimens Irradiation	Evaluated the fuel and fission product retention qualities of tungsten-uranium dioxide dispersions, which are fission heated to anticipate rocket fuel element operating temperatures. Capsules from this experiment were sent to the Battelle Memorial Institute and the Westinghouse Electric Corporation for postirradiation examination.

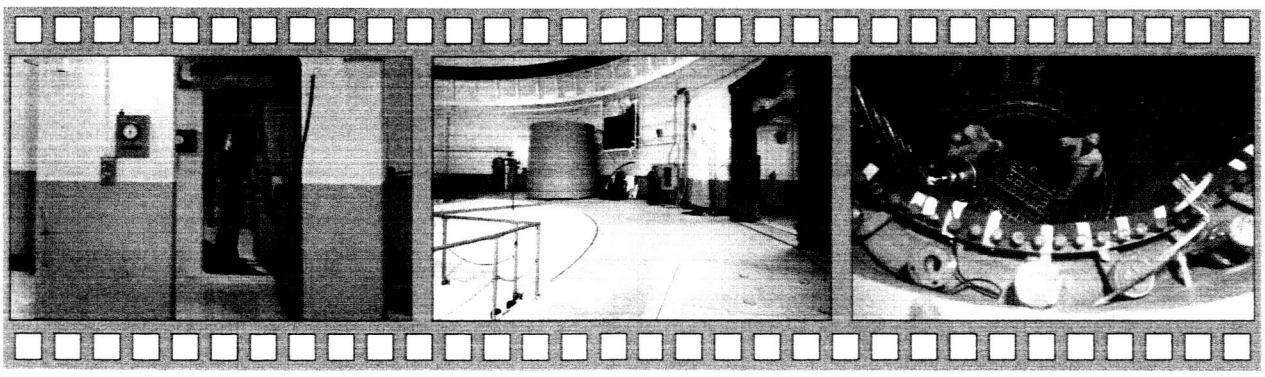


Exp. Number	Cycles	Name	Description
62-12R1	73–75, 77, 78, 81, 82 85–93 95–152	Fueled Material Specimen	A series of tests determined the extent of irradiation uranium dioxide relocation and densification in small fuel pins operating at high-clad surface temperatures. During Cycle 88, engineers irradiated a stainless steel shell-type capsule containing a sealed fuel pin. The purpose of this experiment was to provide the capsule that was required for checkout of the Plum Brook hot cell fracturing device and to determine the extent of pressure buildup in the sealed fuel pin.
62-13	102–103, 105		
62-13R1	42–45	Thermionic Materials Irradiation	
62-13R2	80–116, 118, 119, 124–126	Thermionic Materials Irradiation	
62-14	3–105, 107–152	Irradiation of PBRF Materials	Investigated the long-term effects of critical materials used in the construction of the reactor. For example, in Cycle 4, sixty carbon steel specimens were irradiated that were identical to the material that was used in construction of the reactor pressure tank.
62-15	20–73, 97	Fueled Refractory Compounds Irradiation	Studied the effects of irradiation of refractory fuel components at high specific power to high burnups. This was the first fueled experiment. It was sponsored by Westinghouse.
62-16	64, 65, 76	NERVA Components Irradiation	Included shielding materials tests.

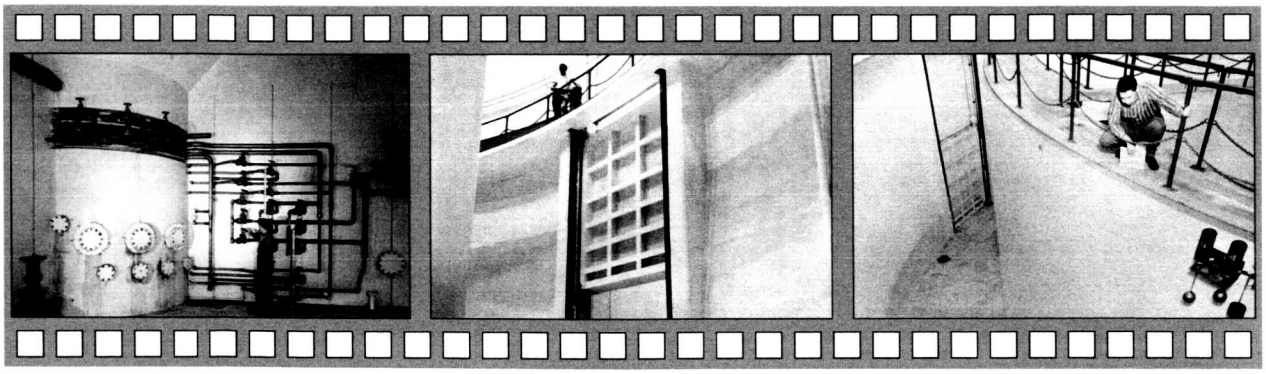


Exp. Number	Cycles	Name	Description
63-01	11–28	Measurements of Materials for SPF Walls	Tested the radiation effects on the full-scale thickness of the Space Propulsion Facility chamber walls. This included aluminum plate and foils and nonborated concrete block.
63-02	25–27, 30	Thermal Conductivity of Refractory Fuel Compounds	Continuously measured the in-pile thermal conductivity of high-density UO_2 fuel at temperatures up to 2,200 degrees Celsius.
63-03R2	82–87, 95–98, 100–112, 119–122, 126–128, 130–134, 137–139	Thermionic Diode Irradiation	The diode was irradiated at defined temperatures to see how it would react. During Cycle 83 the diode would not generate current.
63-03	28–38, 58 60, 76, 93, 94, 100, 115 116, 122	Martin Thermionic Diode Irradiation	Demonstrated the reliable performance of a state-of-the-art thermionic diode in a nuclear reactor.
63-04	76, 78–84 88, 93, 95–98	Thermionic Reactor Fuel Form and Insulator Irradiation	Thermocouple readings were measured as the experiment capsules were subjected to helium and argon at various power levels in the reactor. Polaroid photos were then sometimes taken of the disassembled capsules.
63-05	48, 14, 16, 17, 20, 22, 28, 29, 55, 58, 60	Westinghouse Interim NERVA Experiment	Provided information on materials selection for components used for the NERVA reactor designed by the Westinghouse Astronuclear Laboratory.

Exp. Number	Cycles	Name	Description
63-05R1	30–48, 58	NERVA Transducer Irradiation Program	Sponsored by Westinghouse, this modified the previous 63-05 experiment through the addition of a Charging Table. Other modifications included an HT-1 isolation valve, a capsule seal assembly, a seal pump, controls for the table drive, a pump, a valve motor, and new piping.
63-07	36	Rabbit test of Mallory Material to establish source of tungsten in coolant	Investigated the tungsten 187 buildup in the primary cooling water system during the reactors full-power reactor operation.
63-08	14, 15	Sperry Experiment: Irradiation of Digital Computer Components	Evaluated the radiation temperature resistance of materials used in digital computer switching circuits.
63-09	8, 24–75 122	Nuclear Electric Sub-Systems and Component Irradiation	Investigated the effects of neutron and gamma radiation on the input and output parameters of nuclear-electric components and subsytems. The experiment was for the SNAP-8 program. In Cycle 32 a sheet metal "roof" was constructed over the instrumentation rack to prevent damage from water drippage.
63-09R1	76–79 81–88, 92–96, 99–105, 107–129	Nuclear Electric Subsystems and Components	Testing included a foil plate and holder with thermocouples attached. Argon-41 buildup and biological shielding effectiveness were tested.
63-10	23–30	Alumina Insulators Irradiation	Examined the effects of radiation on the electrical resistivity of high-purity alumina insulators.
63-11	10, 11		Investigated radiation effects on tungsten metal. Most important, it examined the elastic recoil mechanism of tungsten and also tungsten effective resonance integral measurements.



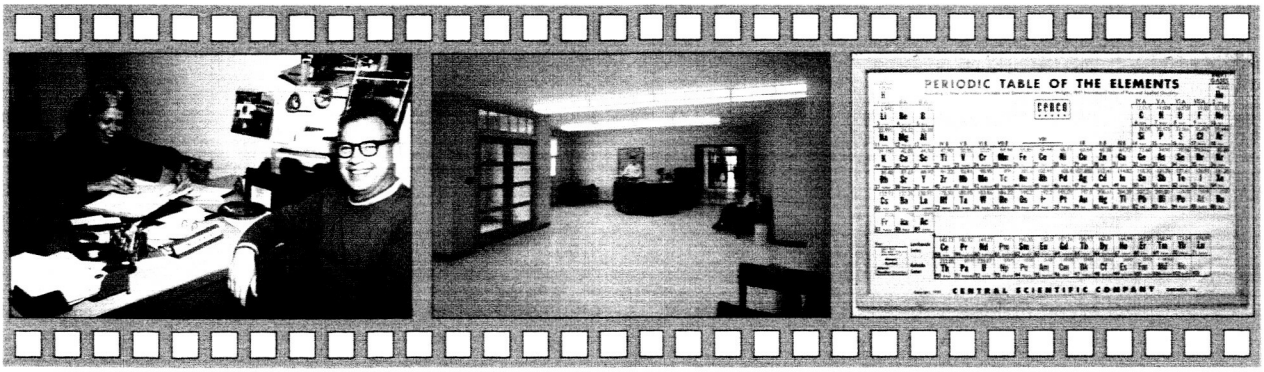
Exp. Number	Cycles	Name	Description
63-11R1	31		Two rabbits with tungsten specimens and flux measuring foils were irradiated for sixty seconds. They were then packaged in the hot lab and sent to the experiment sponsor.
63-12	46–56, 58	Radioscope Electrical Generator	
63-12HL	45, 57–61, 88, 93–96 98–103, 105	Radioscope Electrical Generator	Tested and evaluated the concept of direct conversion of the kinetic energy of radioscope decay into electrical power.
64-01	58	Irradiation of Fuel/Clad Emitters	Performed for General Electric sponsor in California.
64-01R1	38–58	Fuel/Clad Emitter Irradiation	Modifications were made to improve previous experiments.
64-02	12–14, 30–34, 36	Copper Irradiation	Produced the Cu-64 isotope by exposing a high-purity copper foil to a thermal neutron flux. The Cu-64 could be used as a positron source to investigate the behavior of positronium in liquid gases.
64-03	12, 20		Produced a radioactive source (sodium-24) of such magnitude that it can be used to evaluate the decontamination efficiency of the newly built evaporator located at the PBRF waste handling building.
64-04	22, 24–26, 28–43, 50, 51, 65	Concrete Materials Trace Element Control	Determined by neutron activation of concrete samples whether or not the sample batch is satisfactory for the construction of the Space Propulsion Facility biological shield.
64-06	89–92, 95, 97, 98, 100–105, 107–112, 117–119	Radiation Damage Experiments in Ion Complexer and Exchanger Systems	The purpose of this experiment was to procure basic data necessary to determine the feasibility of a concept for control of a water-moderated nuclear reactor.



Exp. Number	Cycles	Name	Description
65-01	40	Production of Uniform Line Source	Thirty-eight target specimens were loaded into two rabbits. Deionized water was added to each of the rabbits, which were then welded shut. One rabbit was then irradiated for just over sixty-one hours and inspected. The rabbit ruptured. A modified vent was designed to enable the rabbits to remain sealed and the experiment continued for a full eighty-hour irradiation.
65-02	41, 42, 44	NaCL Crystals	Three NaCL crystals were placed in polyethylene containers and loaded into three rabbits and irradiated.
66-01	44, 54, 59–62	Irradiation of Various Insulating Materials	Two Al_2O_3 crystals were irradiated for Materials 574.4 MWD in a rabbit. A silicon carbide crystal was also irradiated at sixty megawatts for twenty-four hours and then sent to Lewis Research Center for analysis.
66-03	76, 77, 80–82, 84, 85	Irradiation of Bulk UO_2 Fuel/ Clad Bodies	These experiments included lengthy irradiations. For example, during Cycle 80 a capsule was operated at the desired temperature for 241 hours.
66-03-01	78, 79, 83 86–94	Irradiation of Bulk UO_2 Fuel/ Clad Bodies	
66-03-2	95–98, 100–119, 121, 123	Irradiation of Bulk UO_2 Fuel/ Clad Bodies	In Cycle 105 the capsule was inserted into the reactor tank in one-inch increments to obtain the designed operating temperature. The capsule was then withdrawn completely in one motion, letting the temperature stabilize. This was done fifty times as quickly as possible to study the effects of thermal cycling on the fuel and thermocouples.

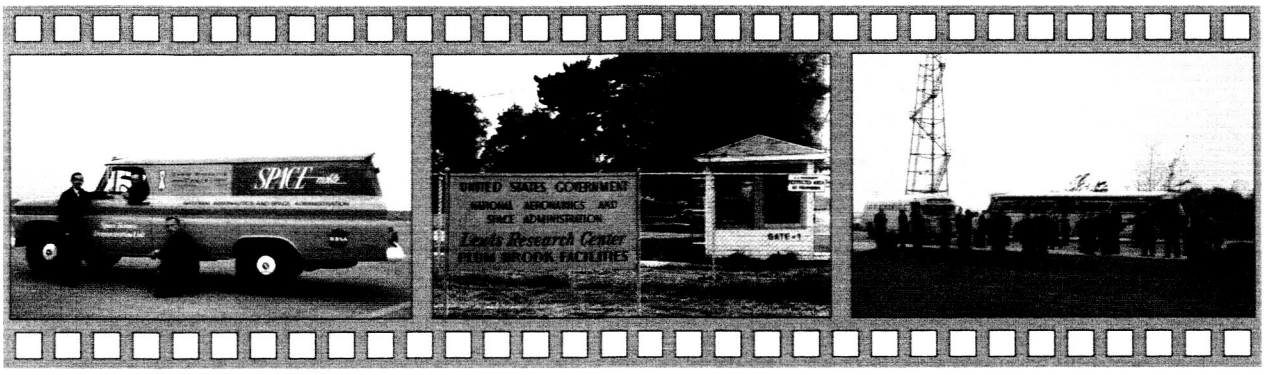
Exp. Number	Cycles	Name	Description
66-05	47, 76	Neutron Irradiation of Ammonium Bromide	A five-milligram sample of ammonium bromide (NH_4Br) was irradiated for thirty minutes at sixty megawatts and sent to Lewis Research Center for analysis.
66-06	92–105, 107–152	Fission Gas Retention Studies	In Cycle 106 the irradiation lasted 330 hours, or 93 percent of the total time available for that cycle. The fuel pin was operated at three temperature levels. Fission gas release data was also collected with the online detection instrumentation. The capsule contents were UO_2.
66-07	59–66	Charpy Impact Specimen Irradiation	Two capsules with weld specimens in aluminum alloy and alloy were initially irradiated for an entire cycle in the reactor.
66-08	73–75, 80, 81, 84, 86–88	Irradiation of a Rare Gas Filled Thermionic Diode	This experiment was installed into the experiment 62-16 (NERVA irradiation) water-cooled capsule.
67-01	58–61, 63–65, 81	Irradiation of Glassy Silicates	Six irradiations were initially performed in the rabbit facility and the specimens were sent to the Case Western Reserve University for analysis.
67-04	87–105, 107–123	Radiolysis of Water	The objective of this experiment was to investigate the pressure buildup and composition of gases resulting from the radiolysis of water in sealed aluminum containers.
67-05	71–82	Micrometeorite Irradiation	Consisted of three powder containers that held two major crystalline silicates of meteorites (Olivine and Enstatite) and six flux monitors.

Exp. Number	Cycles	Name	Description
67-06	76–78, 80–88, 92	Nuclear Reactor Materials Evaluation	Included testing like an experiment in Cycle 93. This included seven wear test specimens for metallurgical examination. Also, eighteen fatigue and six tensile specimens were placed in Hot Cell 1 to await reloading into future capsules for irradiation. Corrosion tests were also started on twenty-one specimens in 200 degrees Fahrenheit deionized water. The fatigue testing equipment was built by the Material Testing Systems (MTS).
67-06-71	94	Nuclear Materials Evaluation Program	
67-06-81	94–96, 98 103, 105, 115–140	Fatigue and Tensile Properties of Irradiated Materials	
67-06-91	99–105, 107–112, 120–127, 129–142	Irradiation of NERVA Materials	Materials included Waspaloy, Inconel, and General Dynamics test specimens.
67-07	76, 77, 79, 81, 82, 91, 94–112, 114–139, 142–150	Irradiation of Gas-Cooled Fuel Pins for Compact Reactors	This experiment arrived at the reactor from Oak Ridge on 21 May 1968. One test (Cycle 103) attempted to measure the diffusion rate of gaseous fission products in a static system.
68-01	76–79–82, 84, 86, 87, 89, 104, 107–109	Irradiation of Plastic Containers	Over twenty-five samples of plastic were irradiated for various lengths of time and analyzed in the hot lab. This increased to fifty samples in Cycle 81. In Cycle 104, fifteen plastic vials that contained lead, aluminum, or air samples were irradiated and analyzed at the radiochemistry laboratory.



Exp. Number	Cycles	Name	Description
68-03	105, 128–139	Nuclear Thermionic Ceramic Insulators	
68-04	89–91, 94, 95	Radioactive Tracer Production for Tektite Research	
68-05	92, 94, 100–102, 105–142	Irradiation of High-Temperature Thermocouples	The temperature of the irradiations was 1,600 degrees Celsius.
68-06	93–101, 103–105	Hot Laboratory Examination of Irradiated Tri-Layer Specimens	Sponsored by Oak Ridge. The high-temperature vacuum furnace was placed in Hot Cell 1. It raised the temperature of the experiment to 2,200 degrees Celsius with a vacuum. In Cycle 105, metallographic specimens were photographed at 250× and 500× magnification.
69-01-1	107–152, 93, 113	Nuclear Experiment Power Reactor Technology Fuel Capsule Irradiations I	Fuel pins received from the experiment sponsor were irradiated. In Cycle 107, samples of stainless steel were irradiated to determine the variation of cobalt content.
69-01-2	111–113, 115–152	Nuclear Experiment Power Reactor Technology Fuel Capsule Irradiations II	
69-01-03	139–152	Space Power Reactor Technology	
69-02	108, 109, 111, 128, 133, 144		
69-03	98–100	Irradiation of Apollo Glycol-Water Solutions	Vials containing glycol-water were irradiated for four hours (Cycle 98) and then analyzed in the radiochemistry laboratory.

Exp. Number	Cycles	Name	Description
70-01	106–107, 109, 112, 115, 116, 118, 123, 126, 128–131, 133, 135, 136, 139, 140, 143–145, 147–152	Irradiation of Lunar Soil	Several vials that contained 1.2 grams of lunar soil (Cycle 106) were irradiated in the rabbit facility for six days. The rabbit was then sent to the hot laboratory where the vials were removed, packaged, and shipped to the experiment sponsor. In Cycle 107, 0.6 grams of lunar soil, one gram of Columbia River basalt, and one gram of ordinary chondrites were irradiated for six days and the samples were sent back to the sponsor.
70-02	118–122, 124–137, 142, 143	Vapor Transport Fuel Pin Experiment	
70-03	111, 112	Irradiation of Pyrolytic Graphite	
70-04	112, 113, 115–119	Irradiation of Grain Boundary Impurities	In Cycle 115, five pairs of grain specimens were irradiated in the rabbit facility for ninety-four hours and then unloaded in the hot laboratory and sent back to the experiment sponsor.
70-05	111, 118, 120, 126, 130–134, 137	Irradiation of Lunar Soil, Meteorites, Terrestrial Rocks, and Standards	
70-06	127, 132–152	Thermionic Reactor Fuel Form Irradiation	
70-07	117, 118	Irradiation of Meteorite Crystals	
70-08	117, 119 120, 122, 123, 125, 126, 128–152	Irradiation of Particulate Materials from Cuyahoga County Air Samples	



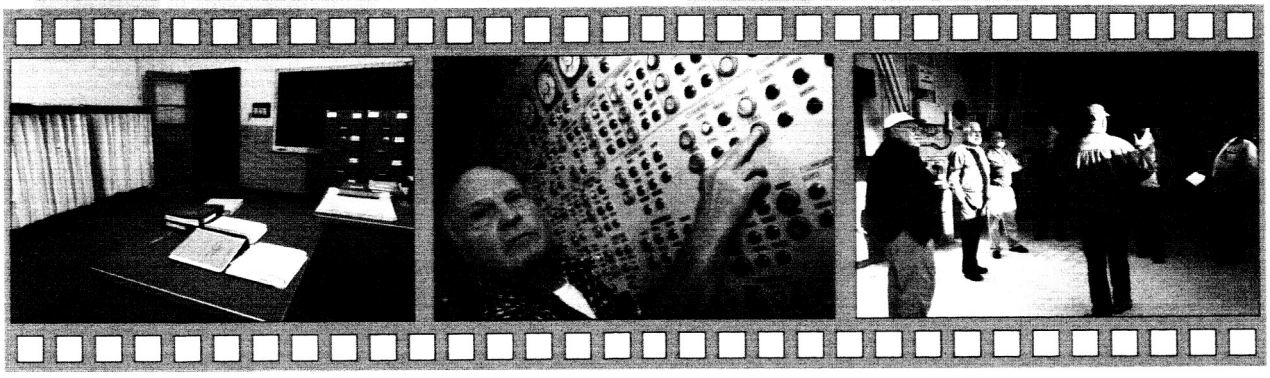
Exp. Number	Cycles	Name	Description
70-09	117, 118, 120, 121, 123, 126, 129, 130, 133, 134, 136, 139–142, 147, 151	Irradiation of Extraterrestrial Material	
70-11	125, 138–144, 146–151	Loss of Coolant Experiment	
70-12	118–146, 148	Irradiation of NERVA Materials at Cryogenic Temperatures	During Cycle 119, 25 specimens of aluminum were loaded into the cryogenic capsule and irradiated at a temperature below seventy-seven degrees Kelvin.
71-02	142, 143, 145 150–152		
71-03	124–129, 131, 133–138, 140, 151	Determination of Mercury and Selenium in Air Particulate	
71-03R1	139, 141–147, 149, 150, 152	Determination of Hazardous Trace Elements in Samples and Fuels	
71-05	128, 132, 133, 136 139	Radioscope F-18 Production	
71-07	135, 136 140–144	Radiation of Reentry Heat Shield Material	

Exp. Number	Cycles	Name	Description
71-08	133, 134	Irradiation of Pure Silicon	
71-09	137–139	Irradiation of Corn	
72-01	143, 150–152		
72-02	140	Irradiation of Thin Silver Films	
72-03	149–152	Nuclear Power Reactor Technology IV	
72-04			
IT-A-I		Neutron Radiographic Facility	This was located in quadrant A. It used a voided tube to direct a neutron beam through a specially designed fifteen-foot-long collimator. The collimated beam of thermal neutrons that emerged provided a three- by thirty-inch area suitable for radiography. For example, in Cycle 89, tests included evaluating different types of X-ray film provided by Eastman Kodak and Agfa-Gevaert. It was also used to irradiate fuel pins.

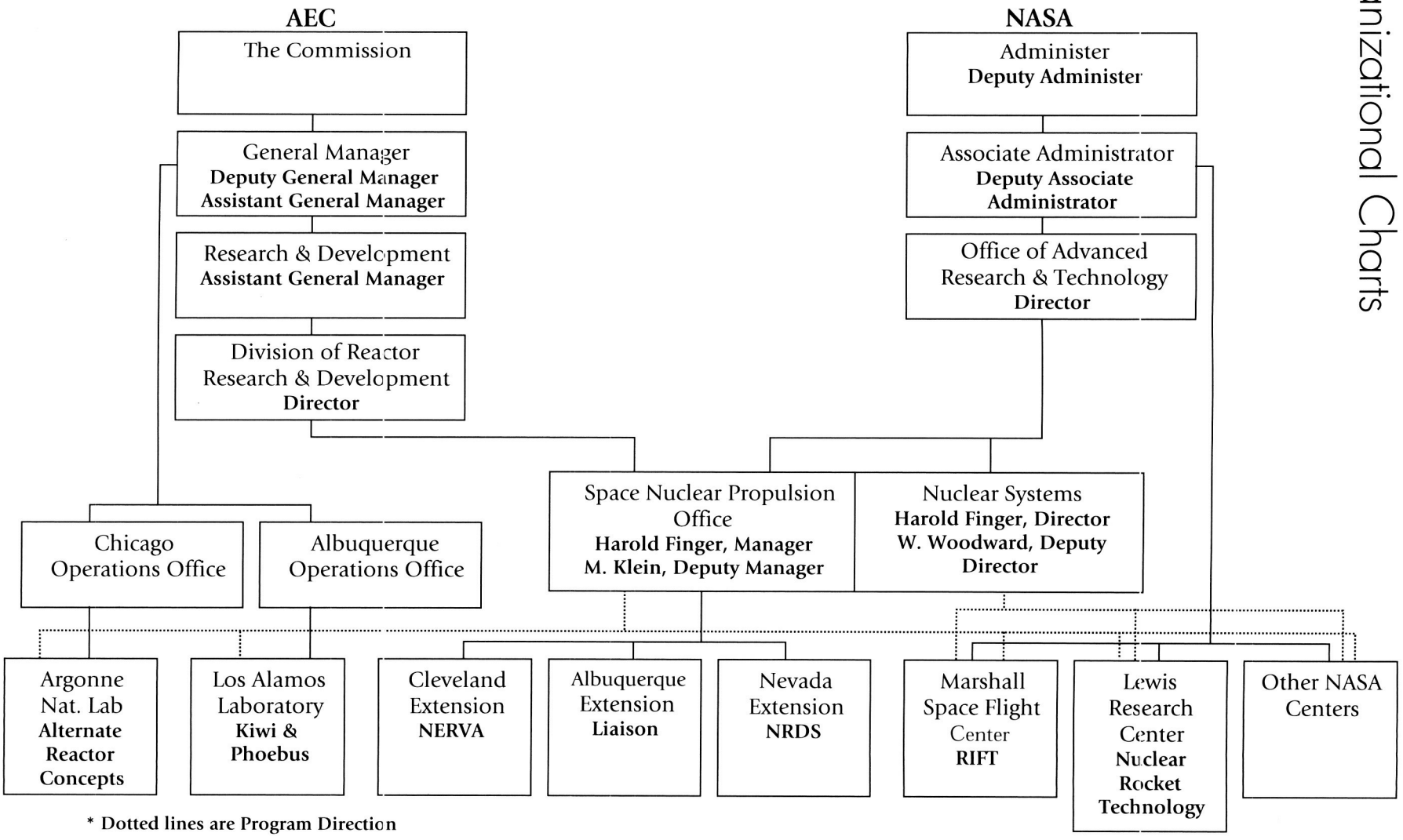
Reactor Cycle Dates

Cycle	Start Date	End Date	Cycle	Start Date	End Date
1	2/12/1963	3/13/1963	45	5/3/1966	5/20/1966
2	3/13/1963	4/29/1963	46	5/20/1966	6/6/1966
3	4/29/1963	8/15/1963	47	6/6/1966	7/18/1966
4	8/30/1963	9/8/1963	48	7/18/1966	7/26/1966
5	9/20/1963	9/26/1963	49	7/26/1966	8/8/1966
6	10/13/1963	10/19/1963	50	8/8/1966	8/24/1966
7	11/1/1963	11/9/1963	51	8/24/1966	9/11/1966
8	11/26/1963	12/6/1963	52	9/11/1966	9/19/1966
9	12/9/1963	12/20/1963	53	9/19/1966	10/26/1966
10	1/10/1964	1/21/1964	54	10/26/1966	11/13/1966
11	1/21/1964	2/5/1964	55	11/13/1966	11/22/1966
12	2/5/1964	2/28/1964	56	11/22/1966	12/14/1966
13	2/28/1964	3/10/1964	57	12/14/1966	2/23/1967
14	3/10/1964	3/25/1964	58	2/23/1967	3/28/1967
15	3/25/1964	4/5/1964	59	3/28/1967	4/15/1967
16	4/5/1964	4/22/1964	60	4/15/1967	5/28/1967
17	4/22/1964	4/29/1964	61	5/28/1967	6/20/1967
18	5/14/1964	6/27/1964	62	6/20/1967	7/8/1967
19	6/27/1964	7/12/1964	63	7/8/1967	8/26/1967
20	7/12/1964	7/25/1964	64	8/26/1967	9/13/1967
21	7/25/1964	8/6/1964	65	9/13/1967	10/15/1967
22	8/6/1964	8/24/1964	66	10/15/1967	10/25/1967
23	8/24/1964	9/30/1964	67	10/25/1967	11/5/1967
24	9/30/1964	10/3/1964	68	11/5/1967	11/19/1967
25	10/3/1964	10/27/1964	69	11/19/1967	12/1/1967
26	10/27/1964	11/15/1964	70	12/1/1967	12/13/1967
27	11/15/1964	12/4/1964	71	12/13/1967	12/29/1967
28	12/4/1964	12/19/1964	72	12/29/1967	1/22/1968
29	12/19/1964	3/7/1965	73	1/22/1968	2/4/1968
30	3/7/1965	3/27/1965	74	2/4/1968	2/17/1968
31	3/27/1965	4/8/1965	75	2/17/1968	6/22/1968
32	4/8/1965	5/6/1965	76	6/22/1968	7/15/1968
33	5/6/1965	5/25/1965	77	7/15/1968	7/31/1968
34	5/25/1965	6/30/1965	78	7/31/1968	8/9/1968
35	6/30/1965	7/24/1965	79	8/9/1968	9/25/1968
36	7/24/1965	8/9/1965	80	9/25/1968	10/27/1968
37	8/9/1965	9/2/1965	81	10/27/1968	11/18/1968
38	9/2/1965	11/7/1965	82	11/18/1968	12/3/1968
39	11/7/1965	11/23/1965	83	12/3/1968	12/24/1968
40	11/23/1965	12/14/1965	84	12/24/1968	1/15/1969
41	12/14/1965	1/14/1966	85	1/15/1969	2/5/1969
42	1/14/1966	1/28/1966	86	2/5/1969	2/20/1969
43	1/28/1966	2/19/1966	87	2/2/1969	3/8/1969
44	2/19/1966	5/3/1966	88	3/8/1969	3/28/1969

Cycle	Start Date	End Date
89	3/28/1969	4/14/1969
90	4/14/1969	5/14/1969
91	5/14/1969	6/11/1969
92	6/11/1969	6/30/1969
93	6/30/1969	7/25/1969
94	7/25/1969	8/22/1969
95	8/22/1969	9/14/1969
96	9/14/1969	10/13/1969
97	10/13/1969	11/3/1969
98	11/3/1969	11/19/1969
99	11/19/1969	12/9/1969
100	12/9/1969	12/24/1969
101	12/24/1969	1/15/1970
102	1/15/1970	2/8/1970
103	2/8/1970	3/1/1970
104	3/1/1970	3/23/1970
105	3/23/1970	4/10/1970
106	4/10/1970	5/18/1970
107	5/19/1970	6/5/1970
108	6/5/1970	6/22/1970
109	6/22/1970	7/9/1970
110	7/9/1970	7/27/1970
111	7/27/1970	8/17/1970
112	8/17/1970	9/8/1970
113	9/8/1970	9/28/1970
114	9/28/1970	10/20/1970
115	10/20/1970	11/8/1970
116	11/8/1970	12/1/1970
117	12/1/1970	12/18/1970
118	12/18/1970	1/18/1971
119	1/18/1971	1/30/1971
120	1/30/1971	2/15/1971
121	2/15/1971	3/7/1971
122	3/7/1971	3/29/1971
123	3/29/1971	4/9/1971
124	4/9/1971	4/25/1971
125	4/24/1971	5/17/1971
126	5/17/1971	6/1/1971
127	6/1/1971	6/26/1971
128	6/26/1971	7/8/1971
129	7/8/1971	8/5/1971
130	8/5/1971	8/23/1971
131	8/23/1971	9/11/1971
132	9/11/1971	10/13/1971
133	10/13/1971	11/1/1971
134	11/1/1971	11/23/1971
135	11/23/1971	12/20/1971
136	12/20/1971	1/14/1972
137	1/14/1972	2/1/1972
138	2/1/1972	2/26/1972
139	2/26/1972	5/19/1972
140	5/19/1972	6/3/1972
141	6/3/1972	6/23/1972
142	6/23/1972	7/11/1972
143	7/11/1972	7/27/1972
144	7/27/1972	8/14/1972
145	8/14/1972	8/29/1972
146	8/29/1972	9/17/1972
147	9/17/1972	10/6/1972
148	10/6/1972	10/29/1972
149	10/29/1972	11/24/1972
150		
151		
152		

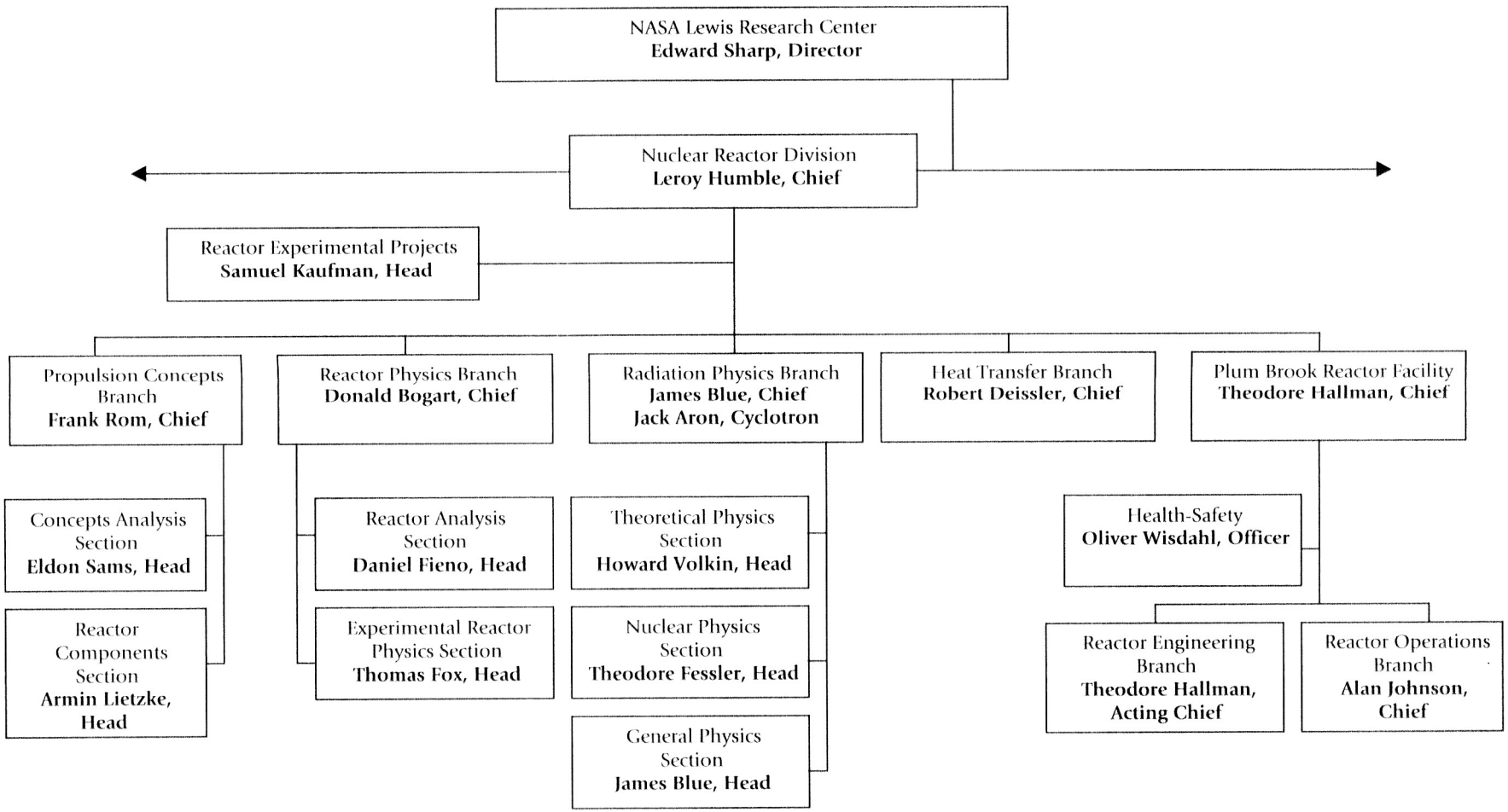


Nuclear Rocket Program Organization (1962)

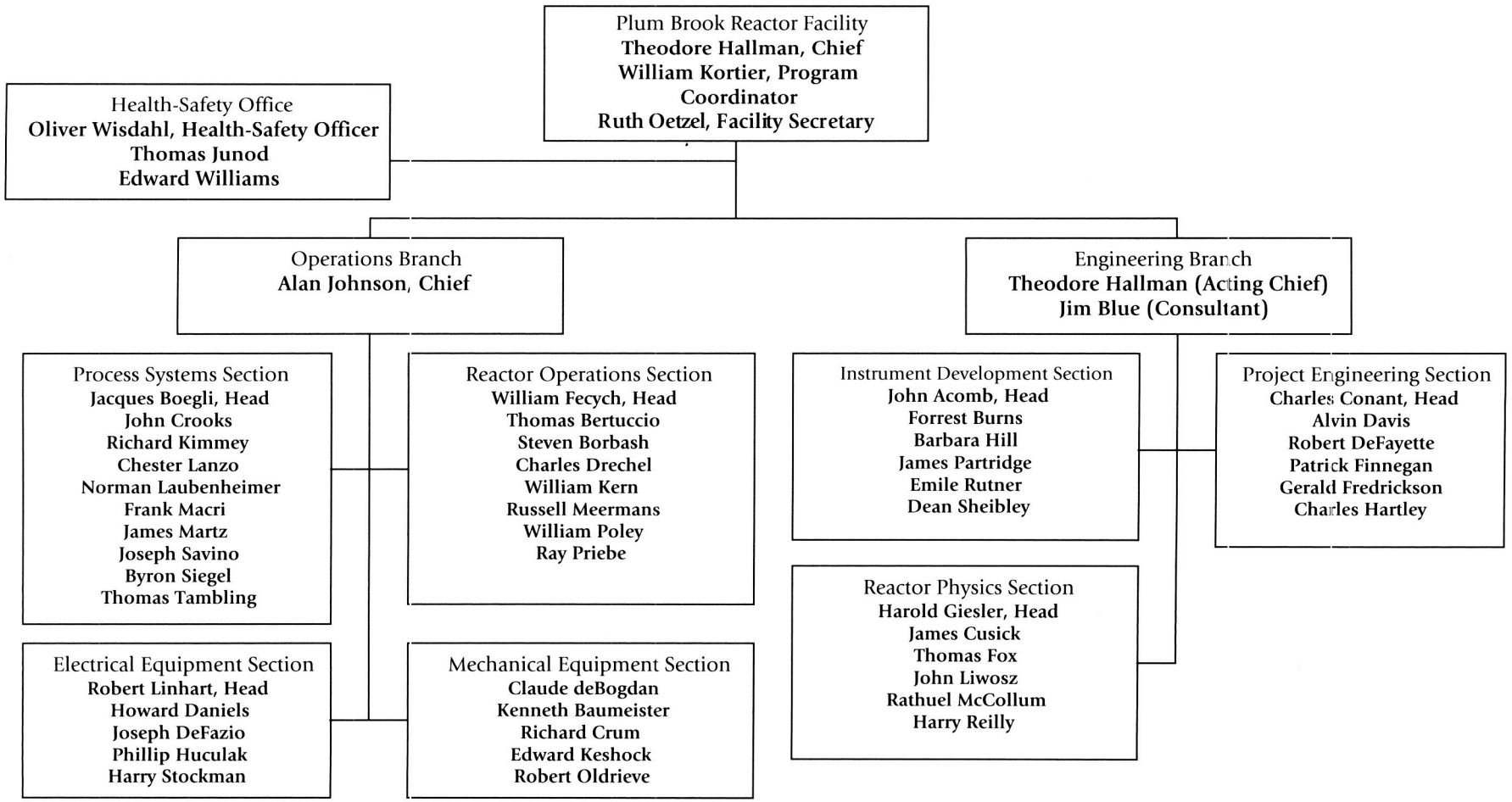


* Dotted lines are Program Direction

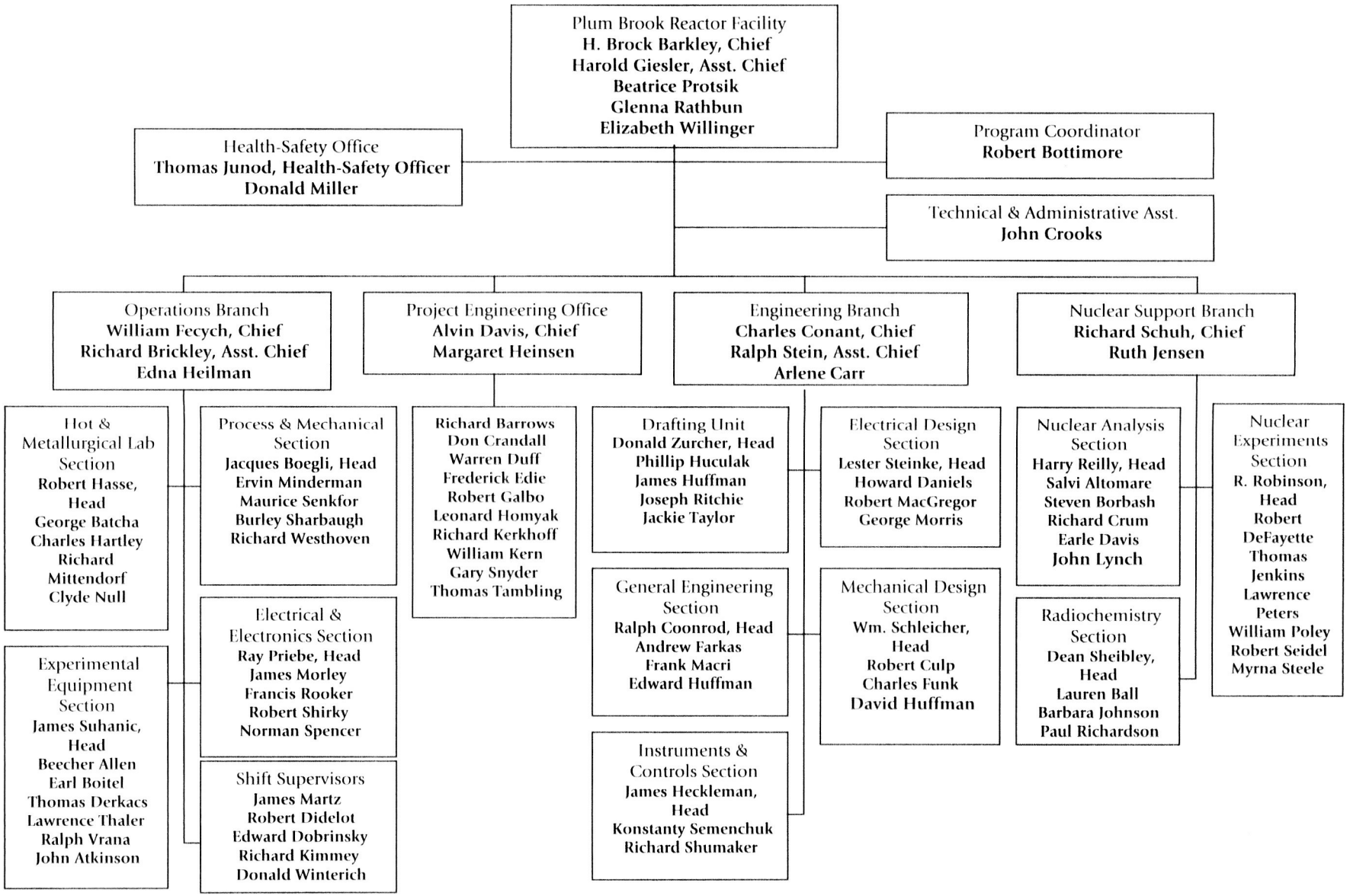
Lewis Research Center Nuclear Reactor Division (1960)



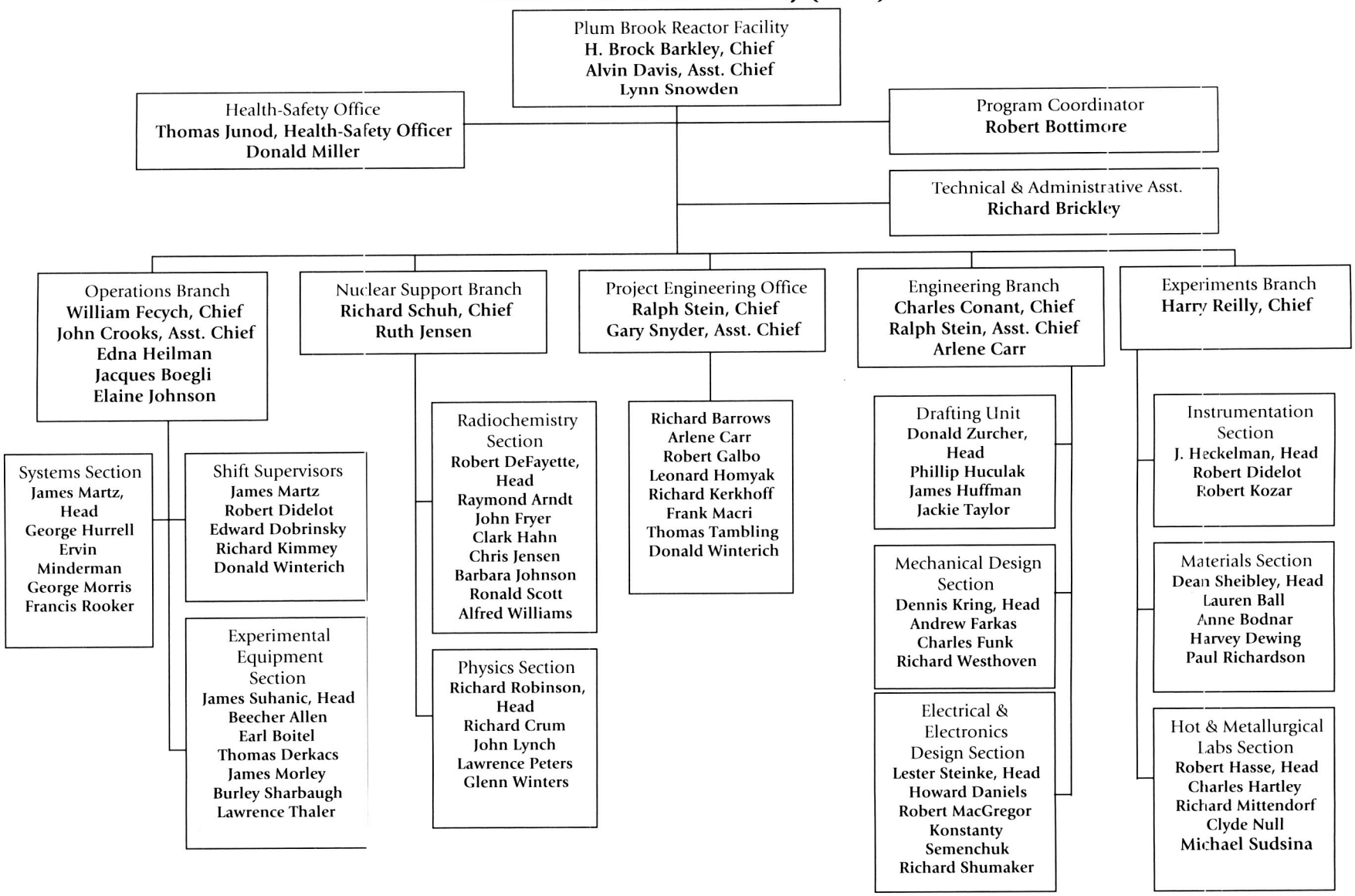
Plum Brook Reactor Facility (1959)



Plum Brook Reactor Facility (1966)



Plum Brook Reactor Facility (1971)



About the Authors

Mark D. Bowles received his B.A. in Psychology (1991) and M.A. in History (1993) from the University of Akron. He earned his Ph.D. in the History of Technology and Science (1999) from Case Western Reserve University. He was the Tomash Fellow (1997–98) from the Charles Babbage Institute at the University of Minnesota. From 1996 to 2004 he was a principal at History Enterprises, Inc., where he coauthored three books with Dr. Virginia Dawson. These included *Taming Liquid Hydrogen* (2004), a history of the Centaur upper stage rocket, which the American Institute of Aeronautics honored with its 2004 History Manuscript Award. Dr. Bowles has also written *Our Healing Mission* (2003), a history of Saint Francis Hospital and Medical Center in Hartford, Connecticut. He is currently vice president and principal at Tech Pro, Inc., and he continues to write books on aviation and aerospace history. He has been married to his wife Nancy for fourteen years. They are raising their three-year-old daughter Isabelle. He can be reached at mark.bowles@case.edu.

Robert Arrighi is an archivist for InDyne, Inc. at the NASA Glenn Research Center supporting the History Office and the Imaging Technology Center. He received his B.A. in History (1997) from Cleveland State University and M.A. in Library and Information Science (2001) from Kent State University. At Kent State, he prepared the Staughton Lynd Collection for the Department of Special Collections and Archives. From 1998–2001 he worked on a number of archival projects for History Enterprises, Inc., which include the Davey Tree Co., Temple Tifereth Israel, Huron Road Hospital, Matrix Essentials, and the National Institutes of Health. Between 2001–03, he worked on a project archiving NASA's Plum Brook Reactor Facility documents and identifying artifacts. During this period, Arrighi cowrote the accompanying documentary script and served as a consultant for the many facets of the reactor historical preservation project. He began working with InDyne, Inc. in June 2003. He can reached at robert.arrighi@grc.nasa.gov.

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—A. Bert Davis, Plum Brook Reactor Facility, Chief

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